Getting Lost on the Road to Decarbonization

Japan's Big Plans for Ammonia

迷走する日本の脱炭素

アンモニア利用への壮大な計画

Climate Integrate

Getting Lost on the Road to Decarbonization: Japan's Big Plans for Ammonia

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Japan is actively promoting the use of hydrogen and fuel ammonia, purportedly in an effort to achievecarbon neutrality. The government is giving its all-out support to expand their use with every tool available, from strategic plans, legislation, subsidies, and debt guarantees, to memorandums of understanding with Southeast Asian countries, and more. The private sector is rushing to join the bandwagon with a wave of new ventures by key players, including power utilities, trading companies, plant builders, shipping companies, and financial institutions. This paper takes a close look at each of the claims being used to justify fuel ammonia as an effective way to achieve carbon neutrality in the thermal power sector by 2050.

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Summary

・ Japan is really the only country in the world to be actively promoting the use of ammonia as a fuel for co-firing with coal for power generation, purportedly to decarbonize the electricity sector.

・ Annual demand for ammonia in Japan is currently at 1 million tons, projected to rise to 3 million in 2030 and 30 million in 2050 due to its expected use as a fuel. Meanwhile, Japanese companies are building a global supply chain projected to reach a scale of 100 million tons annually by 2050.

・ With energy security in mind, the government is trying to expand the use of liquefied natural gas (LNG) by supporting upstream development, boosting its involvement in LNG procurement, and encouraging increased production in countries other than Russia.

・ In order to create demand for ammonia and hydrogen, the government has a policy of treating them as "non-fossil energy sources," even when they are produced from fossil fuels.

・ Fuel ammonia projects are being promoted through various means, including the Green Innovation Fund, Climate Transition Finance, and public/private initiatives, and also within a framework of supporting an energy transition in Asia.

・ Because ammonia is manufactured from fossil fuels and the co-firing mix ratio will remain low for the foreseeable future, its use will do little to reduce CO_2 emissions unless those emissions are addressed through the use of carbon capture and storage (CCS) technologies. The feasibility of CCS is still unproven.

・ If ammonia produced from fossil fuels is co-fired at a 20% mix ratio, the fuel cost will end up being double that of coal; if expected increases in carbon prices are factored in, the fuel cost will be triple that of coal alone.

・ Fuel ammonia is produced by fixing nitrogen from the atmosphere, with the result that its combustion will release nitrogen oxides, which will exacerbate air pollution. Increased nitrogen use will further interfere with the already-unbalanced nitrogen cycle, by increasing nitrogen flows into terrestrial and aquatic systems.

・ No CO_2 emission reduction or cost-related advantages arise from large-scale investments into infrastructure developments for the use of ammonia, such as natural gas extraction, pipelines, construction of delivery supply chains, and upgrades to electricity generation facilities. Conversely, because all of these projects involve environmental impacts, they pose significant risks.

Japan’s policies promoting co-firing with fuel ammonia in the thermal power sector need to be challenged in terms of its contribution to emission reduction, economic rationality, and environmental impact.

I. The push for fuel ammonia

1. Government policy

Approximately 80% of ammonia used in Japan and worldwide is for the production of chemical fertilizers. In Japan, the use of ammonia as a fuel is being strongly promoted based on the premise that it will help realize carbon neutrality. Ammonia is also attracting attention for being easy to store and transport as a hydrogen carrier.

The government aims to co-fire ammonia in existing coal-fired power generation facilities, increasing the co-firing ratio to 20% in 2030 and then to a higher mix after that. Meanwhile, for power generation with LNG, there are also plans to co-fire with hydrogen. The government aims to eventually develop technologies for 100% ammonia and 100% hydrogen combustion as "effective options" to decarbonize power generation (Table 1). However, despite aggressive efforts, the use of ammonia and hydrogen in the electricity mix is still projected to be no more than 1% (9 TWh) of the electricity mix in 2030.[1] Of that amount, ammonia is expected to be used in only about 5% of Japan's total power generation from coal in 2030(total 178 TWh), and a 20% fuel mix of ammonia with coal is expected to apply only to a subsetof all power plants (Table 2). Although there are also moves elsewhere to promote hydrogen and ammonia for uses other than power generation, **Japan is basically the only country in the world where the public and private sectors are unified to proactively promote ammonia and hydrogen as fuels for electricity generation** (Table 3).

Table 1. Government policies to promote the use of fuel ammonia

Policy	Details
Green Growth Strategy (June 2021)	・Ammonia 20% co-firing with coal by 2030 ・Develop technologies to boost the ammonia co-firing ratio, eventually achieving 100% ammonia-fired ・Expand the use of fuel ammonia and build supply chains in Southeast Asia and beyond with the aim of global decarbonization
Sixth Strategic Energy Plan (October 2021)	・Ammonia 20% co-firing with coal by 2030 ・Ammonia and hydrogen account for 1% of electricity mix in 2030 (10% in 2050) ・Domestic (Japan) demand for ammonia: 3M-ton (2030), 30M-ton (2050) ・By 2050, Japanese companies will have created a global supply chain to procure approx. 100M-ton annually (including domestic market) ・Strive to decarbonize with capture/storage/reuse of CO_2 emitted during ammonia production and electricity generation

Source: Climate Integrate

[1] Agency for Natural Resources and Energy (ANRE), "Outlook for Energy Supply and Demand in Fiscal 2030 (related materials)", October 2021, p.73.

Table 2. Electricity mix by source (TWh)

Year	Oil	Coal	LNG	Nuclear	Renewable energy	Hydrogen Ammonia	Total
2019	64 (6%)	327 (32%)	382 (37%)	64 (6%)	186 (18%)	—	1022 (100%)
2030	19 (2%)	178 (19%)	187 (20%)	188-206 (20-22%)	336-353 (36-38%)	9* (1%)	934 (100%)

Source: Climate Integrate from Ministry of Economy, Trade and Industry (METI) materials.[1,2]

* A simple calculation for electricity generated from ammonia and hydrogen in 2030, resulted in 0.8TWh and 0.7TWh,[3] respectively, of which 1% (0.9TWh) was counted in the electricity mix in the METI material.[1]

Table 3. Government's anticipated (direct) uses of hydrogen and ammonia

Anticipated use	Sub-category	Hydrogen	Ammonia
Electricity	Co-fired with coal (0% to 100% of fuel mix)		●
	Co-fired with gas(0% to 100% of fuel mix)	●	
Non-electricity (fuel)	Heat utilization(industrial furnaces, etc.)	●	●
	For marine engines, etc.	● (Short/medium distance)	● (Long distance)
	Fuel cells for mobile/stationary uses, etc.	●	
Non-electricity (feedstock)	Hydrogen reduction steelmaking	●	
	Synthesis of basic chemicals	●	

Source: Climate Integrate from ANRE materials.[4]

2 ANRE, "Comprehensive Energy Statistics", April 2021.

3 Ibid footnote 1, p.62.

4 ANRE, "Measures to promote investment in hydrogen and ammonia supply chains and expand demand", April 2022, p.6.

2. Securing the supply of ammonia

Ammonia can be produced from a variety of energy sources, such as coal, natural gas and renewable energy. That is the basis of government claims that the use of ammonia helps to diversify Japan's procurement sources and boost energy security. On that basis, natural gas is deemed to be an important energy source, so its use for hydrogen and ammonia production is expected to grow.

The world's annual production of feedstock ammonia is currently at 200 million tons, of which 20 million tons are traded internationally, but the entire amount is produced from fossil fuels. In Japan, about 80% of the 1.08 million tons of ammonia used for industrial and fertilizer uses is produced domestically, while the remaining 20% is imported (Table 4).

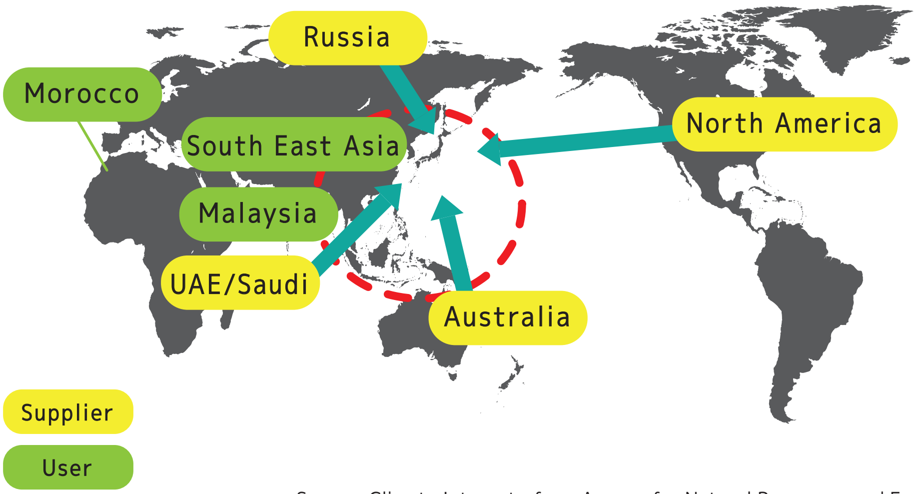
Since existing manufacturing facilities have little excess production capacity and no fuel ammonia market exists, eying ammonia's future use as a fuel use, **the government expects annual domestic demand for ammonia to increase significantly from 1 million tons today to 3 million tons in 2030, and 30 million tons in 2050, greater than current global trade volumes.** The aim is to promote the supply of LNG from Russia, North America, Australia, and other countries, **to build a 100 million ton global supply chain for ammonia**, and to promote mass production through infrastructure development and construction of large-scale supply facilities, thereby reducing prices (Figure 1).

Table 4. Ammonia production volumes, current levels and government projections (million tons)

	Today	2030	2050
World	200 (of which 20 is traded internationally)	—	760
Japan	1 (domestic production 80%, imports 20%)	3	30

Source: Climate Integrate from METI materials.[5]

Figure 1. Countries with potential fuel ammonia supply and demand as anticipated by Japanese government



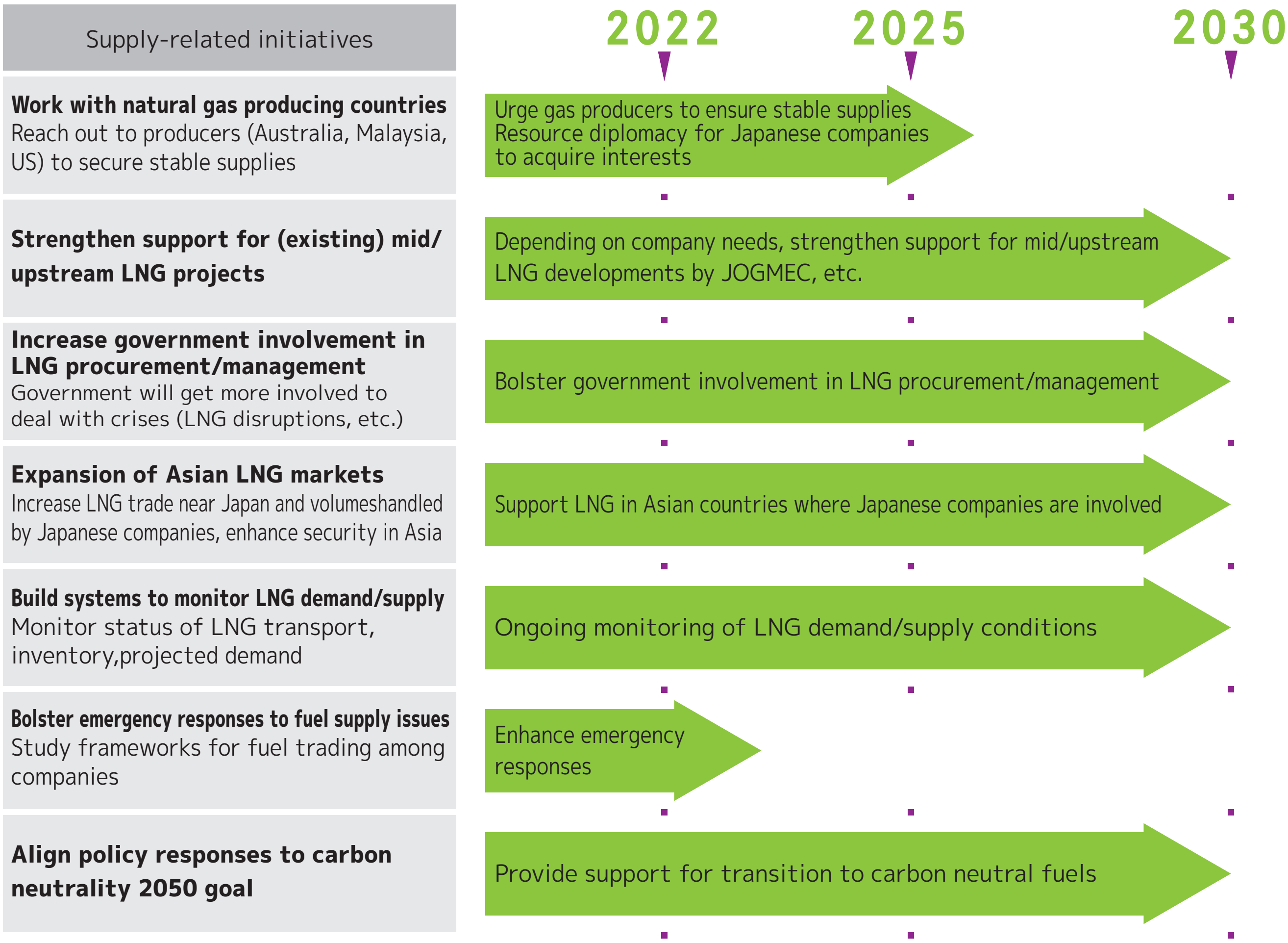
Source: Climate Integrate from Agency for Natural Resources and Energy(ANRE) materials[6]

[5] METI, "Clean Energy Strategy interim compilation", May 13, 2022, p.58-59, and ANRE, "Current situation surrounding hydrogen and ammonia and direction of future consideration", March 29, p.15.

[6] ANRE, "Transition Roadmap for Thermal Power Sector", February 2022, p.48.

Russia's invasion of Ukraine that started in February 2022 has changed the international energy situation. The energy supply crisis and the rise in international prices for energy and other resources is forcing Japan to make some of its most significant structural changes since the oil shocks of the 1970s. **In order to ensure energy security, the government is trying to further expand the use of LNG by encouraging increases in production in countries other than Russia, and this includes bolstering government involvement in support for upstream development and the procurement of LNG.**[7]

Figure 2 Government Policy Directions to Expand LNG use to ensure energy security



Source: Climate Integrate from METI materials[8]

[7] ANRE, "Discussions for formulation of a clean energy strategy (1) (Ensuring energy security, and efforts toward decarbonization)", April 14, 2022, p.28.

[8] ANRE, "Directions for new oil and natural gas policy based on international situation of fossil fuels", April 22, 2022, p.69.

3. Initiatives to promote the use of fuel ammonia

Fuel ammonia was cited as one of 14 expected growth sectors in Japan's Green Growth Strategy (June 2021). The Japan's Strategic Energy Plan (October 2021) indicates a concrete target of 20% for fuel ammonia in the power generation mix in 2030. Various measures are being taken to promote this goal.

(1) Fuel ammonia in legislation

Fuel ammonia and hydrogen are "fossil energy sources" when manufactured from fossil fuels, but the government counts them **as "non-fossil energy sources" regardless of their energy source, to create demand for the future expansion of ammonia and hydrogen use**.

Table 5. Legislative framework to promote fuel ammonia

Law	Details
Non-fossil Energy Act[9] (supply side)	・Hydrogen and ammonia are deemed "non-fossil energy sources" ・Uses legislation to promote thermal power generation equipped with CCS
JOGMEC Act[10] (supply side)	・CCS projects and geological exploration, incl. production, liquefaction, and storage of hydrogen, ammonia, were added to the scope of JOGMEC's investment and debt guarantee operations
Act on Rationalizing Energy Use[11] (demand side)	・Increase the ratio of non-fossil energy used by factories, etc. ・Formulation of medium- to long-term plans for transition to non-fossil energy at business operations of a certain scale and above

Source: Climate Integrate from METI materials.[12]

(2) Green Innovation Fund

Timed with Japan's declaration in 2020 that the country would be carbon neutral by 2050, the government established a 2 trillion yen (170 billion USD) Green Innovation Fund, and launched ten years of support for technology research, development, demonstration and application via the New Energy and Industrial Technology Development Organization (NEDO). Under government plans to allocate up to 68.8 billion yen[13] from these funds to develop fuel ammonia supply chains, about 59.8 billion yen had already been committed as of January 2021 (project size about 81.2 billion yen).[14] The government seeks develop commercial supply chains from Saudi Arabia, the United Arab Emirates, Australia, North America, and other regions, capable of supplying 3 million tons of ammonia annually by 2030. The stated total project costs are pegged at 2.14 trillion yen (initial investment of 640 billion yen, and annual operating costs of 75 billion yen for 20 project years).[15]

[9] Act on the Promotion of Use of Non-fossil Energy Sources and Effective Use of Fossil Energy Materials by Energy Suppliers.

[10] Act on the Japan Oil, Gas and Metals National Corporation, Independent Administrative Agency (JOGMEC).

[11] Act on Rationalizing Energy Use.

[12] METI, "Summary of bill to partially amend the Act on Rationalization of Energy Use to Establish a Stable Energy Demand-Supply Structure", March 2022.

[13] METI, "Discussions for formulation of a clean energy strategy (2) (Status update based on previous discussions)", April 14, 2022, p.54.

[14] NEDO, Green Innovation Fund Project "Fuel Ammonia Supply-chain development" launched, January 7, 2022.

[15] METI, "Discussions for formulation of a clean energy strategy", April 22, 2022, p.14.

(3) Climate Transition Finance[16]

In order to attract funds to transition technologies, the government has deemed bonds and loans that meet four criteria[17] to be "climate transition finance," and has created a roadmap as a guide for key sectors. The Transition Roadmap for the Electricity Sector[18] aims to attract private sector funding for three transition electricity sources (ammonia, hydrogen, and biomass).

Table 6. Government view of low-carbon and decarbonization technologies for transition electricity sources

	Technology	Description
Transition electricity sources	Ammonia co-firing	Ammonia co-firing with coal
	Hydrogen co-firing	Hydrogen co-firing with gas thermal
	Biomass co-firing	Biomass co-firing with coal thermal
Initiatives relying on zero emission electricity sources	Upgrading/updating electrical grids	Upgrade distribution grids for more electricityfrom renewable energy
	Demand response/ electrification	Demand-side decarbonization, electrification, etc.
	Battery storage, pumped hydro, decentralized energy sources	Introduction of battery storage to stabilize electrical grids. Introduction of decentralized energy sources

Source: Climate Integrate from METI materials.[19]

(4) Platforms

The Clean Fuel Ammonia Association was established as a platform for promoting fuel ammonia. Its aim is to mainstream ammonia energy technology and to create a value chain from the supply to the utilization of CO_2-free ammonia. It was set up as a platform for industry, academia, and the government to engage in everything from technology development and assessment, economic assessment, and policy recommendations, to international collaboration. The members include 13 corporate members of the board, 105 general corporate members, and 20 supporting members (foreign companies), as of April 1, 2022. Almost all companies from related industries are involved.

[16] METI, Transition Finance.

[17] Strategy/governance, materiality, scientific basis, and transparency.

[18] ANRE, "Transition Roadmap for Thermal Power Sector", February 2022.

[19] Ibid footnote 18, p.23.

4. Expansion in Asia

(1) Public/private sector initiatives

With the view that Asia needs to have zero-emission thermal power, Japan is working to jointly develop supply chains such as for hydrogen and ammonia, and to deploy fuel ammonia technologies in Southeast Asia. Below are some of the initiatives already launched in Asia.

・ **Asia Energy Transition Initiative (AETI)**

This was launched in May 2021 by Japan's Minister of Economy, Trade and Industry. It has started supporting the development of a roadmap for energy transition in Asia and proposing ideas for an Asian version of transition finance.

・ **Asia Transition Finance Study Group**[20]

This is a private-sector-led group led by the Mitsubishi UFJ Financial Group. The plan is to release guidelines in October 2022 for financial institutions and recommendations for the government to provide funds for the transition sector.

・ **Asia Zero-Emission Community**

In January 2022, the government announced the concept for an Asian Zero-Emission Community. The idea is to promote efforts in Asia such as the development of zero-emission technologies, international joint investment in hydrogen infrastructure, joint fund procurement, technical standardization, and an Asian emissions trading market.

・ **Asia CCUS Network**

This was created jointly as a platform for the public and private sectors in ASEAN countries to promote CCUS in order to abate CO_2 emissions. It is promoting so-called "clean coal" and CCUS.

(2) Bilateral aid

Memorandums of understanding relating to an energy transition have already been signed with Indonesia, Thailand and Malaysia, and Japan has established cooperative relations with them, including support to develop energy roadmaps.

These initiatives to expand into Asia are focused on promoting fuel ammonia co-firing with coal for electricity generation, as demonstrated by Prime Minister Fumio Kishida's announcement at the COP26 climate conference that Japan would replace fossil power with zero-emissions thermal power fired by ammonia and hydrogen.[21]

[20] Asia Transition Finance, October 2021, April 2022.

[21] Prime Minister's speech at the COP26 World Leaders Summit, November 2021.

4. Corporate moves

To date, more than 60 Japanese companies, research institutes and government agencies have been involved in over 80 fuel ammonia projects, ranging from production, transport and storage to use in thermal power generation (Table 7 and Appendix). Many of the fuel ammonia projects are financially supported by the government, including the Green Innovation Fund's "Fuel ammonia supply chain development project," NEDO grant projects such as the "Research, development and demonstration project for ammonia co-firing thermal power technology," the "Blue ammonia production technology development project," and the "Feasibility study project for overseas deployment of high-quality energy infrastructure," but the budgets and project sizes for many of these individual projects have not been made public.

Table 7. Companies involved in fuel ammonia projects (excluding shipping and industry uses)

Up, mid, downstream	Source of ammonia	Japanese entities involved
Upstream manufacturing CCS pipelines procurement	Natural gas only	ENEOS, INPEX, JERA, JOGMEC, JX Nippon Oil & Gas Exploration, Idemitsu Kosan, ITOCHU, Kansai Electric Power, TEPSCO, Toyo Engineering, Nippon Koei, Hokuriku Electric Power, Marubeni, Mitsui & Co, Mitsubishi Gas Chemical, Mitsubishi, Mitsubishi Heavy Industries
	Renewables only	IHI, JICA, Idemitsu Kosan, Osaka University, Kyushu University, National Institute of Advanced Industrial Science and Technology (AIST), De Nora Permelec, J-POWER, Tokyo Institute of Technology, Tokyo University, Toshiba, Toyo Engineering, JGC Holdings, Nissan Chemical, Fukuoka University, Hokkaido University, Marubeni
	Natural gas and renewables	IHI, UBE, Kyushu Electric Power, Sumitomo Chemical, Mitsui Chemicals, Mitsubishi Gas Chemical
	Unknown	ENEOS, IHI, INPEX, JERA, JFE Holdings, ITOCHU ENEX, ITOCHU, "K" Line, Kyushu University, Kyushu Electric Power, Kyoto University, Mitsui O.S.K. LinesSumitomo, Chugoku Electric Power, Chiyoda, Tsubame BHB, Tokyo Institute of Technology, Tokyo Electric Power, Toyo Engineering, Nagoya University, JGC Holdings, National Institute of Technology Numazu College
Midstream transport ship development	Natural gas only	ENEOS, INPEX, JERA, JOGMEC, Idemitsu Kosan, ITOCHU, Kansai Electric Power, TEPSCO, Toyo Engineering, Nippon Koei, Hokuriku Electric Power, Marubeni, Miitsui & Co (MEPAU), Mitsubishi, Mitsubishi Heavy Industries
	Renewables only	IHI, Idemitsu Kosan (IRDA), Mitsui O.S.K. Lines, J-POWER, JGC Holdings, Marubeni
	Unknown	ENEOS, IHI Power Systems, JERA, JFE Holdings, J-ENG, IINO LINES, Idemitsu Kosan, ITOCHU ENEX ITOCHU, "K" Line, Kawasaki Heavy Industries, Kyushu Electric Power, Mitsui O.S.K. Lines, Sumitomo Chugoku Electric Power, Namura Shipbuilding, ClassNK, Nihon Shipyard, NYK Line, Mitsui E&S Machinery Mitsui & Co, Mitsubishi Shipbuilding
Midstream shipping receiving storage	Natural gas only	JOGMEC, Idemitsu Kosan, ITOCHU, Toyo Engineering
	Renewables only	IHI, Idemitsu Kosan (IRDA), Marubeni
	Natural gas and renewables	IHI, Kyushu Electric Power
	Unknown	ENEOS, IHI, JERA, JFE Holdings, Idemitsu Kosan, ITOCHU ENEX, ITOCHU, "K" Line, Kansai Electric Power, Kyushu Electric Power, Mitsui O.S.K. Lines, Sumitomo, Chugoku Electric Power, Toyo Engineering, JGC Holdings, Mitsubishi Shipbuilding
Downstream use in thermal power	Natural gas only	JOGMEC, ITOCHU, Kansai Electric Power, TEPSCO, Toyo Engineering, Nippon Koei, Hokuriku Electric PowercMarubeni, Mitsui & Co, Mitsubishi, Mitsubishi Heavy Industries
	Renewables only	JGC Holdings, Mitsui & Co
	Natural gas and renewables	IHI, Kyushu Electric Power
	Unknown	IHI, JERA, JFE Holdings, ITOCHU, Osaka University, Kyushu Electric Power, Kowa, National Institute of Advanced Industrial Science and Technology (AIST), Japan Petroleum Exploration, Chugai Ro, Chugoku Electric Power, J-POWER, Central Research Institute of Electric Power Industry, Tohoku University, Mitsui & Co, Mitsubishi Heavy Industries

Source: Climate Integrate from press releases of NEDO and other Japanese entities (as of June 16, 2022)

II. A closer look at the use of fuel ammonia

1. CO_2 emission reductions from the use of ammonia

The top justification for promoting the use of ammonia as a fuel is the claim that it leads to reductions in CO_2 emissions in the thermal power generation sector, and that it purportedly leads to decarbonization. Below we examine the CO_2 reductions at each stage: (1) ammonia production, (2) combustion for thermal power generation, and (3) CO_2 sequestration, utilization, and storage.

(1) CO_2 emissions during ammonia production

The main industrial method of producing ammonia is to extract hydrogen from hydrocarbons such as natural gas (methane) through processes such as reforming water vapor, and then to produce ammonia through a reaction with atmospheric nitrogen (Haber-Bosch process).[22] **In short, CO_2 is emitted at the production stage, and it all starts with fossil fuels**. Even with state-of-the-art equipment, **about 1.6 tons of CO_2 are emitted per ton of ammonia produced**.[23] This means that ammonia cannot be claimed to be a "CO_2-free" fuel, because CO_2 is emitted at the production stage.

The largest coal-fired power plant in Japan is in Hekinan City, Aichi Prefecture, and Unit 4 (1 GW) is currently undergoing a government-subsidized trial for co-firing with ammonia. It is Japan's first such attempt at a large commercial coal power plant, and the goal is to achieve 20% co-firing with ammonia in fiscal 2024.[24] According to calculations, it would require 500,000 tons of ammonia per year, which would mean about 800,000 tons of CO_2 being emitted annually for ammonia production.

(2) CO_2 emissions during electricity generation

Because ammonia does not produce CO_2 emissions during combustion, the only CO_2 emissions reduced at the power plant would be the ammonia portion of the fuel burned. **With 20% co-firing in coal-fired electricity generation, the use of ammonia will reduce CO_2 emissions during combustion by 20%**. The government's goal, however, is to achieve 20% co-firing in 2030. Obviously, 80% of the fuel would still be coal. In the future, if 100% ammonia combustion is achieved, CO_2 emissions during combustion will be zero. But there are no prospects for this to happen. It will be difficult to achieve zero carbon emissions during electricity generation through co-firing or 100% ammonia combustion, which means that the use of coal is likely to continue up to 2050.

Adding in the emissions from ammonia production, CO_2 emission reductions would be 4% for 20% co-firing, 10% for 50% co-firing, and just 21% for 100% ammonia combustion.[25] Thus, unless emissions are abated with CCS, the emission reductions will be negligible (Figure 3).

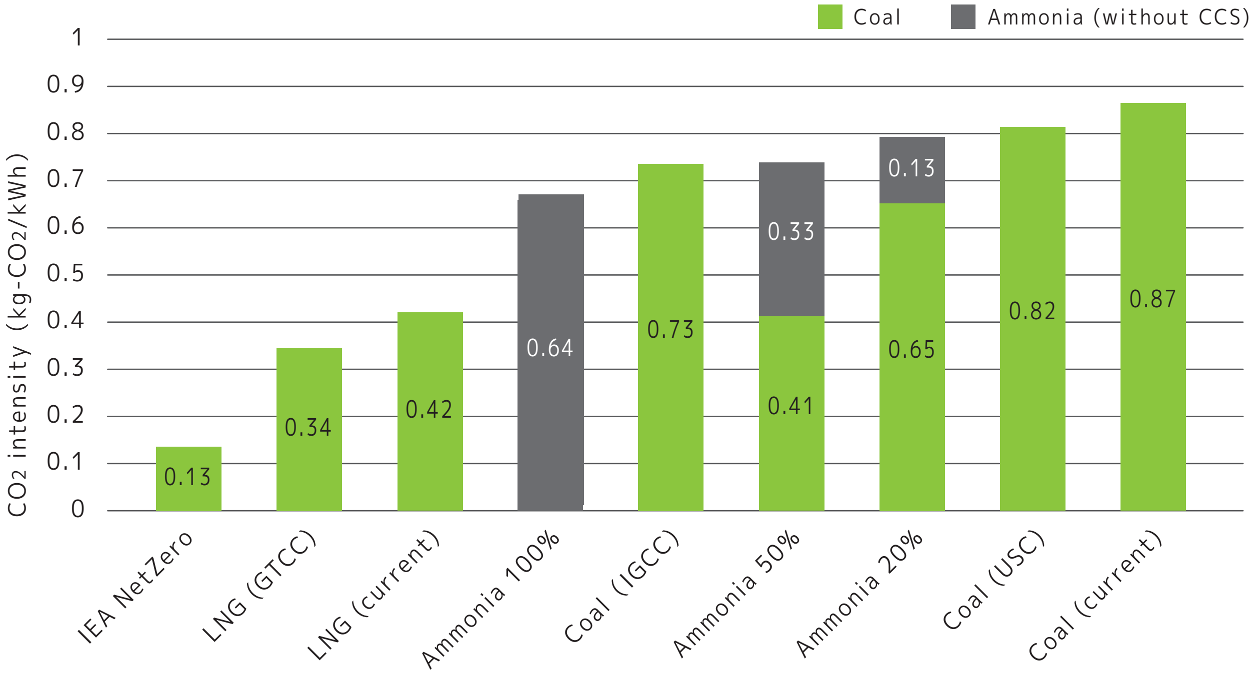
[22] Another type of production process involves water electrolysis using renewable energy, and work is currently under way to find ways for production at scale with this method. Research is also under way regarding electrochemical synthesis of ammonia, which does not require hydrogen production, and there is some anticipation that it may be the main means of production in the future (IEEJ, 2017).

[23] METI, (1.6 t-CO_2) and Kiko Network, "Challenges for Hydrogen and Ammonia Electricity Generation", (1.58 t-CO_2), p.13.

[24] JERA, "Adoption of a demonstration project for ammonia co-firing in large commercial coal-fired power generators", May 24, 2021.

[25] Ibid footnote 23, based on Kiko Network estimates.

Figure 3. CO_2 emissions coefficients for each coal power technology and fuel type



Source: Climate Integrate from Ministry of the Environment material[26]

* Estimate of impacts of co-firing with ammonia based on USC, with reference to Kiko Network[23]

(3)Emission reductions with CO_2 capture, utilization, and storage

CO_2 capture and storage (CCS) technologies capture carbon emitted during production and electricity generation, and store it underground or elsewhere. Recently, it is also referred to as CCUS, with the addition of "utilization." Deeming this to be an innovative technology, the government has been conducting research and development since the 1990s. At one point, it aimed to have this technology in commercial use by 2020, but that goal has been elusive. **The government is working to develop legislation with the goal of commercially launching CCS by 2030**.

However, the only result in Japan to date is at a large-scale trial at Tomakomai City, Hokkaido, which achieved 300,000 t-CO_2 of compression and injection in 2019 (for comparison, annual emissions from just one plant--the Hekinan coal-fired thermal power plant (Units 1 to 5)--are about 25 million t-CO_2). In addition, annual CO_2 emissions from coal-fired power plants amount to about 260 million t-CO_2, and even if some CCS projects have been launched by 2030, zero emissions will be a difficult goal to reach. The government aims to achieve annual storage of 120 million to 240 million t-CO_2 in 2050. However, the future potential for massive commercial operations presents a host of challenges, including securing and paying the cost of sites for carbon storage, the level of technology maturity required, and environmental impacts. Even if CCS becomes feasible in practice, carbon capture rates would reportedly still be around 80 to 85%, which means that zero emissions would still not be possible.

[26] Ministry of the Environment, "Coal Fired Power Export Fact book 2020", May 2020, p.71.

Table 8. Government policies regarding CCS

Policy	Details
Sixth Strategic Energy Plan (October 2021)	・ Develop suitable sites and technologies and prepare the necessary business environment for commercialization of CCS in 2030
CCS long-Term Roadmap (May 2022)	・ **Legislation is being prepare with a target of commercial launch by 2030** ・ Annual CO_2 storage in 2050 is anticipated to be 120 million to 240 million tons

Source: Climate Integrate

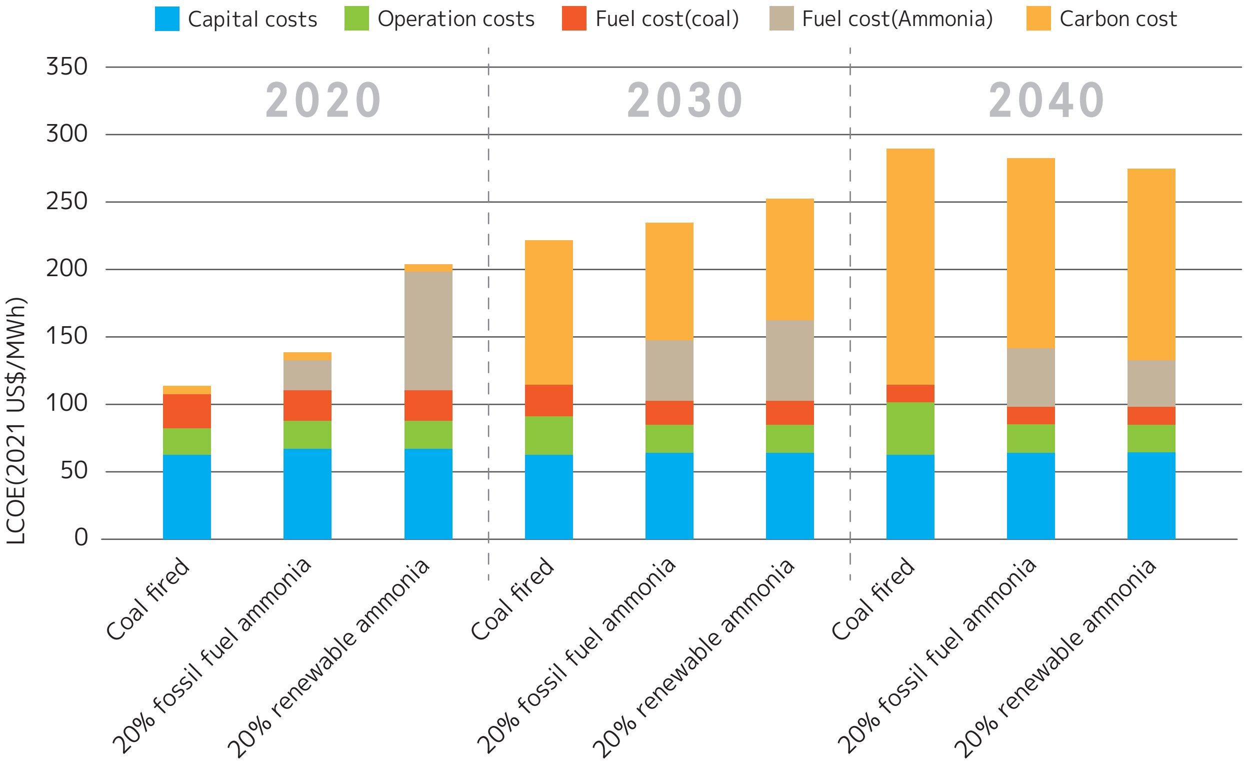
This analysis reveals that no evidence currently exists that the use of fuel ammonia can achieve zero emissions. There is no basis in reality for any efforts to move forward based on claims of being “zero carbon,” “CO_2-free,” “zero emissions” or “decarbonized fuel.”

2. Economics

Costs are a major challenge for partial co-firing or 100% combustion with fuel ammonia. The UK thinktank TransitionZero has stated that **with 20% co-firing using ammonia produced from fossil fuels, fuel cost will be twice that of coal-firing alone, and when future carbon price increases are factored in, fuel cost rises to three times that of coal**. Transition Zero also estimates that ammonia co-firing technologies will only start to be competitive with coal in 2040 (assuming a high carbon price of US$205/t-$CO_2$ in 2040, resulting in a prohibitively expensive levelised cost of electricity (LCOE) at US$ 280 /MWh, or about 32 yen/kWh)). At that point, co-firing with ammonia made with renewable energy would be cheaper than ammonia co-firing with coal.[27] Even if proponents are willing to pay such high costs, co-firing with ammonia is unlikely to reduce CO_2 emissions unless CCS is used.The government has estimated the cost of generating electricity from coal at 12.5 yen/kWh in 2020, 12.9 yen/kWh with 20% ammonia co-firing, and 23.5 yen/kWh with 100% ammonia combustion. However, these costs do not include CCS to abate CO_2 emissions.

[27] TransitionZero, “Coal-de-sac: Advanced Coal in Japan“, February 14, 2022.

Figure 4. Costs of electricity generation by co-firing with ammonia



Source: TransitionZero

3. Environmental impacts: Disruption of the nitrogen cycle

Ammonia (NH3) is a compound of nitrogen and hydrogen, typically produced with the Haber-Bosch process by fixing nitrogen, which is present in massive quantity in the atmosphere. However, its use exacerbates other environmental problems. Nitrogen builds up in terrestrial ecosystems in the form of nitric acid and nitrite, and nitrous oxides are produced as byproducts. The result has been the disruption of the nitrogen cycle, leading to many environmental problems, from eutrophication of freshwater and seawater, to air pollution, oxidant pollution, acid rain, and serious groundwater contamination caused by nitrate nitrogen. Nitrate nitrogen becomes nitrite nitrogen in the body, which causes oxygen deficiency.

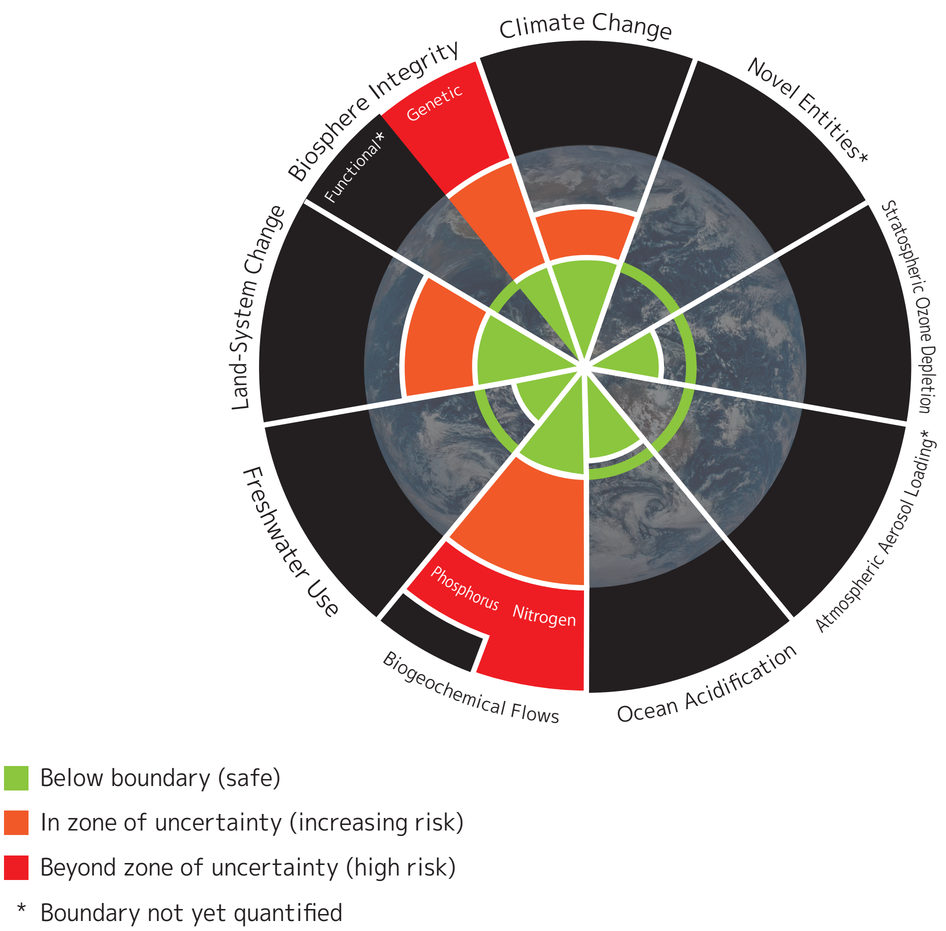
This is a problem with fuel ammonia as well. Fixing nitrogen from the atmosphere to produce ammonia for use as fuel will interfere with already-imbalanced nitrogen cycle and further increase the nitrogen load on terrestrial, marine and aquatic systems.

The government claims that 20% co-firing trials have confirmed that this can be controlled, but the reality is that the claims have never been tested at scale, so it is likely that nitrogen will remain in the land in some form. No solutions have been found to deal with the problem of nitrogen compounds and nitrous oxides if ammonia ever reaches 100% combustion rates, but powerful denitrification equipment would likely be necessary.

This Planetary Boundaries[28] figure shows that we are already exceeding boundaries in two of nine categories (specifically, nitrogen in biogeochemical flows, and biosphere integrity). Excessive nitrogen loads, especially in marine and aquatic systems, have significant negative impacts on biodiversity, due to the expansion of "dead zones" where living organisms cannot survive.

Nitrogen loads in the ecosystem already significantly exceed boundaries and must be reduced. The idea of co-firing with ammonia is going in entirely the opposite direction. Co-firing with ammonia also poses serious problems in terms of the nitrogen cycle.

Figure 5. Planetary Boundary



Source: Climate Integrate from the website of Stockholm Resilience Center

[28] A concept of boundaries that scientifically define the range within which the Earth can safely accommodate humanity activities. Developed by Johan Rockström from the Stockholm Resilience Centre and others.

Conclusion

The use of ammonia may contribute to decarbonization in some non-electricity applications, and it could conceivably contribute to future CO_2 emission reductions through the electrolysis of water using renewable energy. However, Japan stands alone as an example of government and the private sector working closely together to aggressively promote co-firing technology to use ammonia in coal-fired power generation, in an attempt to decarbonize electricity generation.

Ammonia produced today comes entirely from fossil fuels and emits CO_2. The government and private sector are moving toward a target of 20% ammonia co-firing in 2030, even though little or no reduction in CO_2 emissions can be expected. Looking deeper, this target means Japan would continue using electricity generated from coal even after 2030, which conflicts with the complete coal phase-out by 2030 Japan should be achieving in order to be aligned with the world's 1.5°C target. In addition, as long as Japan is promoting co-firing or 100% firing with ammonia, it will be difficult to decarbonize thermal power generation unless CCS is successfully commercialized on a massive scale. Indeed, the government is planning major investments into CCS, but the technology is still rife with challenges.

It has been well-documented that the most cost-effective way to decarbonize the electricity sector is to make the transition to renewable energy generated from solar and wind power.[29] That approach has huge potential. Conversely, no CO_2 emission reduction or cost-related advantages arise from large-scale investments into infrastructure developments for the use of ammonia, such as natural gas extraction, pipelines, construction of delivery supply chains, and upgrades to electricity generation facilities. Because all of these projects involve environmental impacts, they pose significant risks.

Japan's policies promoting co-firing with fuel ammonia for the thermal power generation sector need to be challenged.

[29] Intergovernmental Panel on Climate Change (IPCC), Working Group III report, Summary for Policymakers (SPM), Figure 7.

Annex: List of fuel ammonia projects

	Project	Source of ammonia			Japanese entities involved
		Natural gas	Renewables	Unknown	
1	Demonstration trial for blue ammonia transport from UAE	✓	-	-	Idemitsu Kosan
2	Feasibility study on ammonia co-firing for coal-fired power plant in Suralaya (Indonesia) and assessment of entire value chain	✓	-	-	Mitsubishi, Mitsubishi Heavy Industries, Nippon Koei
3	Feasibility study to introduce ammonia co-firing by retrofitting an existing gas-fired power plant and study establishment of a value chain in Indonesia	✓	-	-	Mitsubishi Heavy Industries, TEPSCO
4	Renewal of MOU with Indonesian national oil company Pertamina	✓	-	-	JOGMEC, JX Nippon Oil & Gas Exploration
5	Production and sales project for blue ammonia and blue methanol in Canada	✓	-	-	ITOCHU
6	Joint research agreement on feasibility of clean ammonia production	✓	-	-	INPEX, JERA, JOGMEC
7	Joint CCS study for clean fuel ammonia production	✓	-	-	JOGMEC, Mitsubishi Gas Chemical, Mitsubishi
8	Study on collaboration with Saudi Aramco to create a CO_2-free hydrogen and ammonia supply chain	✓	-	-	ENEOS
9	Production of blue ammonia	✓	-	-	Mitsui & Co
10	Technology development for blue ammonia production	✓	-	-	Unknown
11	Feasibility study on blue ammonia production technology	✓	-	-	INPEX
12	Feasibility study on ammonia value chain between Eastern Siberia and Japan	✓	-	-	JOGMEC, ITOCHU, Toyo Engineering
13	Agreement with US-based Denbury Inc. for CO_2 transport and storage for fuel ammonia production	✓	-	-	Mitsubishi
14	Preliminary feasibility study on blue ammonia production in United States	✓	-	-	Mitsui & Co
15	Joint CCS study for clean fuel ammonia production in Western Australia	✓	-	-	JOGMEC, Mitsui & Co (MEPAU)
16	Feasibility study on creating a clean fuel-ammonia supply chain from Australia to Japan	✓	-	-	JOGMEC, Marubeni, Hokuriku Electric Power, Kansai Electric Power
17	Joint study to secure stable clean ammonia	✓	✓	-	Mitsui Chemicals, Mitsubishi Gas Chemical, Sumitomo Chemical, UBE
18	Study for promotion of clean ammonia use *	✓	✓		Sumitomo Chemical
19	Feasibility study project for upgrading the environmental performance of coal-fired power generation by ammonia co-firing (Malaysia)	✓	✓	-	IHI
20	Joint study on establishment of an ammonia supply chain using existing facilities at Idemitsu's Tokuyama complex	✓	✓		IHI, Idemitsu Kosan
21	Joint study on creating a supply chain (production to utilization) and establishment of a receiving and shipping system	✓	✓	-	Kyushu Electric Power
22	Research project to introduce green hydrogen and ammonia in Azerbaijan	-	✓	-	JGC Holdings
23	Feasibility study for commercialisation of green ammonia fuel production using an existing fertiliser plant in Indonesia	-	✓	-	Toyo Engineering
24	Joint study for green ammonia business development	-	✓	-	J-POWER
25	Green ammonia electrolytic synthesis	-	✓	-	Idemitsu Kosan, Tokyo University, Kyushu University, Osaka University, Tokyo Institute of Technology (Planned subcontract to Nissan Chemical, Toshiba, and National Institute of Advanced Industrial Science and Technology (AIST))
26	Joint studies and research in green hydrogen and ammonia project	-	✓	-	Idemitsu Kosan (IRDA)
27	Joint development agreement for green hydrogen and green ammonia production	-	✓	-	Marubeni
28	Feasibility study project on ammonia co-firing for coal-fired power plants in Morocco	-	✓	-	Mitsui & Co
29	Research and development of a new ammonia synthesis system using hydrogen from renewables	-	✓	-	Japan International Cooperation Agency (JICA)
30	Study on green ammonia project in Tasmania, Australia	-	✓	-	IHI, Marubeni
31	Joint study on creating a green ammonia business supply chain in Australia	-	✓	-	Mitsui O.S.K. Lines
32	Development of innovative ammonia electrolytic synthesis technology	-	✓	-	IHI, De Nora Permelec, Hokkaido University, Tokyo University, Fukuoka University
33	Concept study for ammonia and liquefied CO_2 dual-purpose carrier	-	-	✓	Mitsubishi Shipbuilding, Mitsui O.S.K. Lines
34	Concept study on ammonia floating storage and regasification unit (FSRU)	-	-	✓	Mitsubishi Shipbuilding, Mitsui O.S.K. Lines, Kansai Electric Power
35	Publication of "Guidelines for Alternative Fuel Vessels (Version 1.0)" *	-	-	✓	ClassNK
36	Demonstration study of 20% ammonia co-firing in a 1 MW class coal-fired power plant (grant project)	-	-	✓	IHI, JERA
37	86,700 cubic meter LPG-fuelled LPG/ammonia carrier	-	-	✓	ENEOS Ocean, Kawasaki Heavy Industries
38	Research and development to expand CO_2-free ammonia fuel use in thermal power plants (commissioned project)	-	-	✓	Chugai Ro, Osaka University, National Institute of Advanced Industrial Science and Technology (AIST), Central Research Institute of Electric Power Industry, J-POWER
39	Collaboration to develop LNG value chain project and create a large-scale supply chain for hydrogen and ammonia	-	-	✓	JERA
40	Construction contract for LPG and ammonia carrier dual-fuelled by LPG and heavy oil	-	-	✓	Mitsubishi Shipbuilding, Namura Shipbuilding, Mitsui O.S.K. Lines (Phoenix Tankers PTE)
41	LPG-fuelled low-speed engine (ME-LGIP)	-	-	✓	Mitsui E&S Machinery
42	Construction contract for a LPG-fuelled large LPG and ammonia carrier	-	-	✓	Kawasaki Heavy Industries, NYK Line
43	Financing and operational cooperation with Abu Dhabi National Oil Company (ADNOC)	-	-	✓	Japan Bank for International Cooperation (JBIC)
44	Design and development project of Ammonia Ready LNG-fuelled ship *	-	-	✓	NYK Line

45	Approval in principle (AiP) for Ammonia Ready LNG-fuelled Panamax Bulk Carrier *	-	-	✓	ClassNK, Planning and Design Center for Greener Ships
46	MOU to consider cooperation in ammonia gas turbine business	-	-	✓	IHI
47	Joint study on creating an ammonia supply chain	-	-	✓	JERA, Idemitsu Kosan
48	Project to assess the safety of ammonia in marine fuel use *	-	-	✓	Mitsubishi Heavy Industries, NYK Line
49	Procurement order for an ammonia-fuelled marine main engine *	-	-	✓	Mitsui E&S Machinery, Mitsui O.S.K. Lines
50	Basic research on ammonia-fuelled decarbonised next generation high performance industrial furnace *	-	-	✓	Hokkaido University, Tohoku University, Hiroshima University, Rozai Kogyo, Sanken Sangyo
51	Development of a large ammonia carrier fuelled by ammonia	-	-	✓	Mitsubishi Shipbuilding, Namura Shipbuilding, Mitsui O.S.K. Lines
52	Development of a large ammonia receiving terminal by improving ammonia receiving and storage technology	-	-	✓	IHI
53	Study on technologies for co-firing and 100% firing with ammonia	-	-	✓	IHI
54	Approval in principle for an ammonia-fired VLCC (very large crude carrier) *	-	-	✓	Nihon Shipyard
55	Approval in principle for the design of an ammonia-fuelled Panamax bulk carrier *	-	-	✓	ClassNK, Planning and Design Center for Greener Ships
56	Development of ships with ammonia-fuelled engines made in Japan	-	-	✓	IHI Power Systems, J-ENG, Nihon Shipyard, NYK Line, ClassNK
57	Joint acquisition of design approval for ammonia-fuelled car carriers *	-	-	✓	"K" Line, Shin Kurushima Dockyard, ClassNK
58	Integrated project for development and deployment of ammonia-fuelled ships *	-	-	✓	NS United Kaiun, Mitsui E&S Machinery, ITOCHU, "K" Line, Nihon Shipyard
59	Collaboration to create a domestic value chain for ammonia in Japan and to develop innovative vessels including ships using zero-emission fuels	-	-	✓	Uyeno Group, NYK Line
60	Licence agreement for ammonia production process	-	-	✓	JGC Holdings
61	Development and demonstration of new catalysts for ammonia production	-	-	✓	Chiyoda, Tokyo Electric Power, JERA (Planned subcontract to Kyushu University, Kyoto University, Tsubame BHB, Tokyo Institute of Technology, Nagoya University, National Institute of Technology Numazu College)
62	Re-entry into the ammonia transport business	-	-	✓	Mitsui O.S.K. Lines
63	Fixed-term charter contract for ammonia carriers	-	-	✓	Mitsui & Co, IINO LINES
64	Joint study on energy transport and supply infrastructure	-	-	✓	JFE Holdings, Japan Petroleum Exploration
65	Development and demonstration of 100% ammonia combustion technology in gas turbines	-	-	✓	IHI, Tohoku University, National Institute of Advanced Industrial Science and Technology (AIST) (Planned subcontract to JERA)
66	Joint development of marine ammonia fuel supply chain in Singapore *	-	-	✓	ITOCHU ENEX, ITOCHU, Mitsui O.S.K. Lines
67	MOU for collaboration to develop a CCS project in Thailand	-	-	✓	INPEX, JGC Holdings
68	Development of advanced technology for naphtha cracking furnaces *			✓	Mitsui Chemicals, Maruzen Petrochemical, Sojitz Machinery, Toyo Engineering
69	Joint feasibility study of decarbonisation initiative using hydrogen and ammonia in Johor, Malaysia	-	-	✓	ITOCHU
70	Feasibility study on simultaneous ammonia/biomass co-firing at an USC coal power plant in Malaysia and feasibility study on deployment in South-East Asia	-	-	✓	Chugoku Electric Power, Mitsui & Co, IHI
71	Strategic cooperation agreement with Russian company PAO NOVATEK	-	-	✓	JBIC
72	Consideration of cooperation in hydrogen and ammonia supply in Keihin waterfront area (Yokohama and Kawasaki)	-	-	✓	ENEOS, JERA, JFE Holdings
73	Consideration of converting Yamaguchi refinery into receiving station for next-generation energy (hydrogen, ammonia, etc.)	-	-	✓	Idemitsu Kosan
74	Development of combustion technology for fuel ammonia in industrial furnaces *	-	-	✓	Taiyo Nippon Sanso, AGC, National Institute of Advanced Industrial Science and Technology (AIST), Tohoku University
75	Shipbuilding for a newly developed 86,700 cubic meter LPG-fuelled LPG/ammonia carrier	-	-	✓	"K" Line, Kawasaki Heavy Industries
76	GENESIS Matsushima project to upcycle an existing power plant by adding gasification facilities	-	-	✓	J-POWER
77	Supply of ammonia fuel for marine use in Japan, and joint development of a supply base *	-	-	✓	Uyeno Group, ITOCHU ENEX, ITOCHU, UBE
78	Accommodating ammonia-fuelled tugboats in Yokohama Port (linked to development of ships with ammonia-fuelled engines made in Japan) *	-	-	✓	Yokohama City
79	Consideration of cooperation for introduction of hydrogen and ammonia	-	-	✓	JERA, Chugoku Electric Power, Kyushu Electric Power
80	Study on practical applications of ammonia-fueled ammonia gas carrier *	-	-	✓	Nihon Shipyard, ClassNK, NYK Line
81	Alliance agreement for engineering, procurement, construction (EPC) project of fuel ammonia plant	-	-	✓	JGC Holdings, Toyo Engineering
82	Development and demonstration of high-ratio-mix ammonia co-firing technology in coal boilers (including 100% ammonia combustion technology)	-	-	✓	IHI, JERA, Mitsubishi Heavy Industries
83	Technical/economic feasibility study for ammonia co-firing in coal-fired power plant	-	-	✓	IHI, Kowa
84	MOU on comprehensive cooperation on decarbonization	-	-	✓	JGC Holdings
85	Study on ammonia fuel supply for ships and basic approval for bunkering vessels	-	-	✓	Sumitomo, "K" Line
86	Development of decarbonised industrial furnace with innovative ammonia combustion *	-	-	✓	Osaka University, Chugai Ro, Tokyo University

* Shipping and industry uses (not included in Table 7)

Source: Climate Integrate from press releases of NEDO and other Japanese entities (as of June 16, 2022)

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Through integrated approaches to connect scientific, political, and social dimensions,
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