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Climate-Tech to Watch: Green Ammonia

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Green ammonia has attracted plenty of recent attention. The technology is promising, but cost reductions, demonstrations, infrastructure, and market growth are all still needed if it is to realize its potential.

KEY TAKEAWAYS

- The transition to net-zero CO_2 global energy systems will require countries to deploy a range of transformational technologies. Green ammonia is envisioned to play a role in transitioning heavy industry and agriculture systems as well as being a low-carbon energy carrier.
- Current ammonia production is responsible for 1.8 percent of global CO_2 emissions. Producing the hydrogen needed to make ammonia from water electrolysis and renewable energy (e.g., green ammonia) is a route to significantly reduce carbon emissions.
- The global green ammonia industry is still in its early stages, with only a few pilot projects in operation, but it has attracted the attention of industry players and governments around the world.
- Bringing the costs down, improving efficiency, increasing production scale, and expanding pipeline infrastructure will be crucial for new applications and the increased demand envisioned.
- DOE should enable the use of green hydrogen in existing ammonia production by supporting demonstration-scale projects coupled with RD&D efforts in catalysis, reactor design, and separations to further reduce costs. Public funding for demonstrations of new end uses will help create a market for green ammonia.

WHAT IS IT?

Ammonia, a colorless gas widely used to produce fertilizer, has become the subject of intense interest due to its promise as an energy carrier and zero-carbon fuel. Producing ammonia is energy intensive and typically involves a reaction of fossil-derived hydrogen and nitrogen obtained from the atmosphere. Most of the associated carbon emissions are from the use of natural gas as a feedstock for the hydrogen precursor. Alternatively, producing the hydrogen from water electrolysis wherein renewable electricity is the energy source (e.g., green ammonia) is a route to significantly reduce the carbon emissions from ammonia production.[1]

WHY IS IT IMPORTANT? GREEN AMMONIA AS A CROSSCUTTING CLIMATE SOLUTION

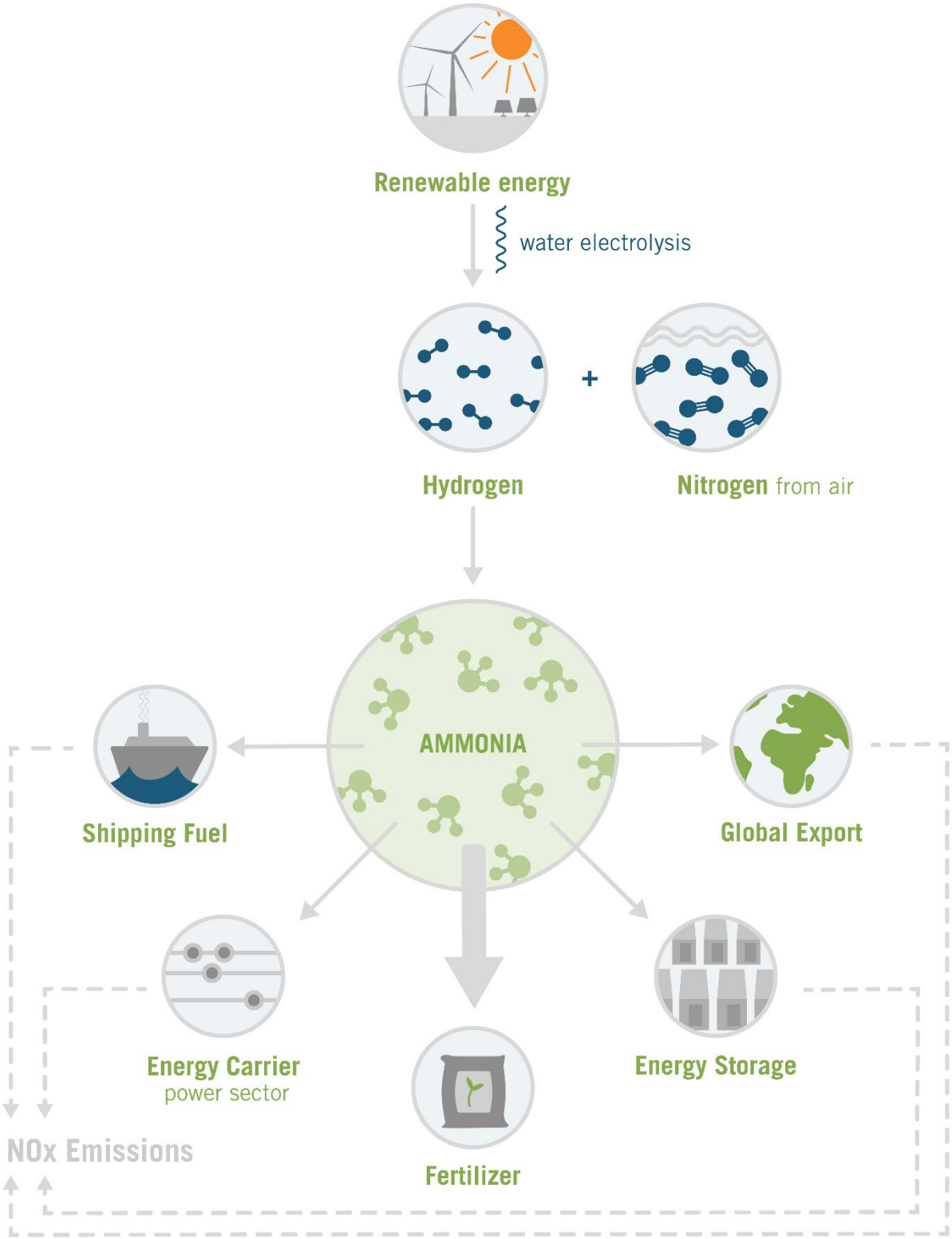
The transition to a net-zero carbon dioxide (CO_2) global energy system will require countries to deploy a wide range of transformative low-carbon technologies in order to change how energy is generated, transported, and used. Green ammonia is envisioned to play several roles in breaking the dependencies between energy use and CO_2 emissions (e.g., decarbonization) in heavy industry and agriculture systems as well as being a low-carbon energy carrier.[2]

Current global ammonia production, mainly for use as a feedstock to produce fertilizer, is roughly 194 million ton per year and is responsible for 1.8 percent of global CO_2 emissions.[3] Widespread adoption of green ammonia could therefore significantly reduce agriculture's carbon footprint. A recent study estimates that using green ammonia for fertilizer, heat, and fuel could reduce the fossil energy consumption of corn and other small grain crops by 90 percent.[4]

Beyond agriculture, green ammonia offers additional decarbonization options across other industries. It has a high energy density and—unlike hydrogen—does not need to be stored at extremely low temperatures or high pressures, making it easier to transport.[5] These properties are especially relevant in the maritime sector, which is responsible for roughly 3 percent of global emissions.[6] The International Energy Agency (IEA) sees ammonia as a vital solution for decarbonizing shipping, potentially addressing 45 percent of energy demand by 2050.[7]

Green ammonia may also play an important role as an energy carrier in the power sector. It is a good candidate for transporting hydrogen, and can also be used as a long-duration storage medium to provide electricity at times when renewable generation is low. In this case, variable renewable energy (e.g., wind, solar) could be used to make hydrogen and then ammonia, which could be stored. Whenever energy use is needed, the ammonia could be reconverted to provide that energy. And, as storing power for inter-seasonal periods is costly, ammonia could reduce costs in this area.[8]

Figure 1: Role of green ammonia in future energy systems



Scaling up global ammonia production does, however, come with attendant risks. Ammonia is toxic, and though it is not itself a greenhouse gas, ammonia leaks can interact with other airborne chemicals to form fine particulate matter that ultimately affects air quality.[9] In addition, burning ammonia instead of fossil fuels generates nitrogen oxides (NOx), although existing technologies can minimize these emissions.[10] Figure 1 illustrates the landscape of ammonia generation and uses.

GLOBAL PROGRESS

The global green ammonia industry is still in its early stages, but it has attracted the attention of industry players and governments around the world, with pilot plants already in operation, including those in Britain and Japan that are powered by wind energy. Several companies also have commercial-scale plants in development. Norwegian chemical company Yara is building a plant to produce 3,500 tons of green ammonia annually in Australia. The largest project announced to date is in Saudi Arabia. Once complete in 2025, it will provide 1.2 million tons of green ammonia annually.[11]

In parallel, many companies and governments are supporting research into new applications for green ammonia. Mitsubishi is developing turbines to directly combust ammonia, and Japan has funded a project to retrofit ships to run on ammonia by 2024. Leading maritime engine manufacturers MAN and Wärtsilä have both announced plans to make internal combustion engines that can run on ammonia commercially available by 2024.[12]

PROGRESS IN THE US

Green ammonia is currently only produced at a pilot scale in the United States, but major efforts are underway to achieve commercialization. The Department of Energy (DOE) has played an instrumental role in funding early-stage research, development, and demonstration (RD&D) projects for producing green ammonia. Through the Advanced Research Projects Agency-Energy (ARPA-E) REFUEL program, DOE has funded component technologies and pilot systems for the production and use of ammonia as a carbon-neutral liquid fuel. Following the REFUEL program, ARPA-E awarded an additional $10 million to the Research Triangle Institute to demonstrate the production and use of renewable ammonia.[13] Additionally, the DOE Office of Basic Energy Science has funded six fundamental research projects to help decarbonize the existing ammonia market.[14]

CF Industries, the world's largest ammonia producer, announced plans to build a green ammonia plant in 2020 in Louisiana. It will produce 20,000 tons of green ammonia per year once it begins operations in 2023.[15]

KEY POLICY ISSUES: INNOVATION TO ADDRESS COST AND SCALE.

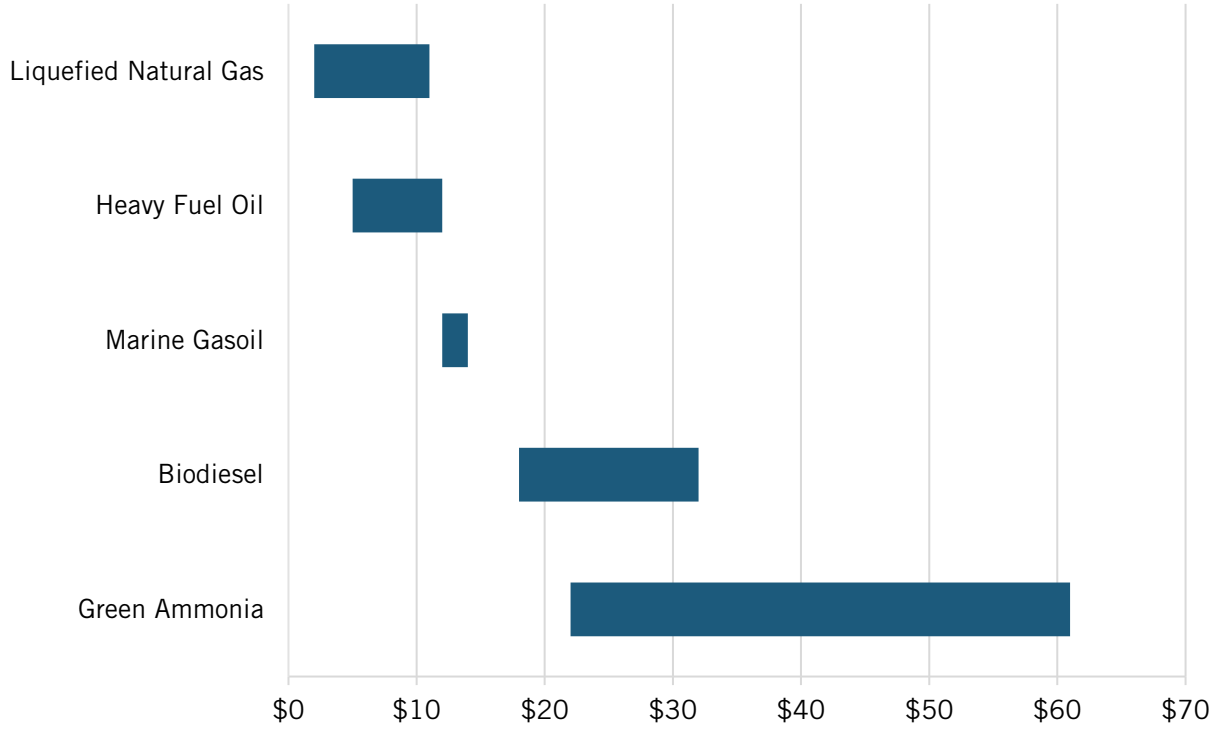
Efforts by industry to produce green ammonia at scale are aided by federal support for low-carbon hydrogen production. The Bipartisan Infrastructure Law appropriates $9.5 billion to support the growing clean hydrogen market, and the Inflation Reduction Act of 2022 provides further incentives, including a production tax credit.[16]

Despite recent incentives, green ammonia still faces significant barriers to becoming competitive, especially in new end uses such as shipping. At its current cost—roughly $794 to $1,543 per ton—green ammonia is unlikely to be competitive in the global fertilizer market or as

a solution in other sectors. For existing applications, green ammonia will have to meet the costs of fossil fuels, which range from $121 to $375 per ton.[17]

For green ammonia to become a viable low-carbon fuel for shipping, it will need to be economically competitive with the fossil fuels that are currently used in shipping, including heavy fuel oil (HFO) and marine gasoil (MGO). Green ammonia will also have to compete against other low-carbon alternatives such as biodiesel.[18]

Figure 2: Comparative cost ranges for shipping fuel, per gigajoule[19]



Using ammonia for power generation or energy storage introduces additional economic and technical considerations. One such factor is round-trip efficiency, which measures the efficiency of converting renewable energy to ammonia, storing and transporting the ammonia, and then converting the ammonia back into electricity. The end-to-end efficiency of green ammonia is only between 11 and 19 percent, meaning the resulting power will be between five and nine times more expensive than the original power used to produce the ammonia. Modeling of ammonia-fired power in Japan finds that generating power from ammonia would cost about twice as much as renewable energy due to the low round-trip efficiency. While the efficiency may improve, green ammonia is unlikely to become a competitive power source.[20]

Bringing the costs down, improving efficiency, increasing production scale, and expanding pipeline infrastructure will be crucial for new applications and the increased demand envisioned. DOE plays an important role in overcoming these barriers by funding RD&D to accelerate innovation. Research into such areas as new catalysts, reactor designs, and separation strategies can improve the efficiency of ammonia production and bring down costs. ARPA-E funds several RD&D projects related to low-carbon ammonia through the $36 million REFUEL program. Public

RD&D funding is also needed to address environmental and safety challenges associated with ammonia combustion, including developing and testing methods to reduce NOx emissions. [21]

Policies that support end-user demand for green ammonia are also essential. For example, DOE recently funded two projects to study the use of ammonia in gas turbines.[22] Similarly, the International Maritime Organization is working to develop guidelines for the safe use of ammonia as a marine fuel, which would help expand demand.[23]

LOOKING FORWARD

Green ammonia has attracted plenty of recent attention. The technology is promising, but cost reductions, demonstrations, infrastructure, and market growth are all still needed if it is to realize its potential. In addition to the cost reductions, government RD&D is needed to support efforts to remove technical barriers such as low round-trip efficiency.

Acknowledgments

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About This Series

Innovation to make energy clean, affordable, and reliable should be a central goal of climate and energy policy, because the sobering reality is that climate change caused by unabated combustion of fossil fuels will continue until clean systems match conventional systems in price and performance. But the good news is that there is a wide range of opportunities to do just that—if innovation policy helps the private sector unlock them.

In this series of briefings, ITIF's Center for Clean Energy Innovation provides overviews of promising climate technologies, highlighting progress that has been made on them, what still needs to be done, and what the United States can do to bring them to maturity so they can contribute to the transition to net-zero emissions.

About the Author

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