

## The Evolution of Clean Hydrogen: Clean Ammonia Development Projects as a Clean Hydrogen Derivative

Article

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We recently attended a hydrogen-focused conference in Houston and came away with two major impressions:

First, the US green hydrogen market is perceived to be in a holding pattern as interested parties work through regulatory uncertainty stemming from the new Trump administration and its approach to section 45V tax credits, which would support green hydrogen project development.

Second, many hydrogen market players remain resilient and patient in their dedication to developing the hydrogen ecosystem and finding ways to progress the greater hydrogen value chain in spite of the regulatory uncertainty and related market challenges.

These trends match our recent experience advising on hydrogen matters. One green hydrogen pathway is evolving to take the lead: green hydrogen projects with green ammonia as the end product or “hydrogen-derivative.” Recent examples include Woodside Energy’s acquisition of OCI Global’s clean ammonia project in Beaumont, Texas, and Avina’s development of the Nueces Clean Ammonia production facility near Corpus Christi, Texas.

In this article we share key considerations and related risks (along with risk mitigants) in developing and financing clean hydrogen to clean ammonia projects. A note on “green” versus “clean” hydrogen and ammonia. Our usage of the term “clean” with respect to hydrogen or ammonia is intended to encompass both “green” and “blue” hydrogen or ammonia (the color designations are explained below). Recent developments suggest that the hydrogen market will likely evolve toward a clean hydrogen model as opposed to a strictly green hydrogen one. Our use of “clean ammonia” should be read as ammonia produced from clean hydrogen. While the tax credits for clean hydrogen production in the US are critically important, we do not address those

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credits in this article as that subject matter is outside of the authors' expertise and warrants an entire article to itself.

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## What Is Clean Ammonia and Why Is it Important?

Ammonia is currently one of the most widely produced chemicals globally, with an annual output of about 176 million tons and its production consuming approximately 1.8 percent of the world's total energy. In addition to the high energy demand needed to produce ammonia is a substantial carbon footprint – ammonia production emits roughly 500 million tons of carbon dioxide annually, due primarily to the use of fossil fuels in the production of hydrogen. The development of ammonia projects that incorporate clean hydrogen is vital to ongoing efforts to facilitate mass decarbonization.

To better understand ammonia, it is helpful to review the color classification system commonly applied in the context of energy. The classification does not describe the quality or purity of ammonia but instead focuses on the carbon emissions associated with its production based on the energy source or, in the case of blue ammonia, the carbon mitigation technique utilized in its production processes. Ammonia is generally categorized into four colors: (i) brown, (ii) grey, (iii) blue, and (iv) green. In some cases, additional colors, such as pink for ammonia produced utilizing nuclear energy, may also be used.

Brown and grey ammonia are classified based on the energy feedstock used to produce the hydrogen input needed for the Haber-Bosch process (an industrial process by which ammonia is synthesized by combining nitrogen and hydrogen gases under high pressures and elevated temperatures in the presence of an iron-based catalyst). Brown ammonia uses coal gasification to produce hydrogen while grey ammonia, the most widely produced form today, uses steam methane reforming (SMR) to extract hydrogen from natural gas. Blue ammonia, on the other hand, involves capturing the carbon released during SMR with carbon capture and utilization (CCU) technology.

Green ammonia refers to ammonia produced using renewable energy sources, making it a carbon-free alternative to traditionally produced ammonia. Whether ammonia qualifies as "green" depends on the applicable regulations. Under the strictest definition, no carbon emissions can result from any stage of the ammonia production process. In other words, the hydrogen production, nitrogen separation from the air, and energy required to power the Haber-Bosch process and related facilities must produce zero carbon emissions. The biggest hurdle to producing green ammonia is the production of green hydrogen.

Green hydrogen is produced using renewable energy sources that have no associated carbon emissions. The most widely used method for producing green hydrogen is water electrolysis. In this process, electricity is passed through water to decompose it into hydrogen and oxygen. Renewable power-to-hydrogen projects, most notably solar and wind projects, are a popular way

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to power water electrolysis with green energy. However, the intermittent nature of renewable energy means the process can only be conducted while the sun is shining, or the wind is blowing. Therefore, to produce green hydrogen at scale, energy storage mechanisms will need to be developed and implemented to store surplus renewable energy which can be used to supplement supply during periods of low renewable energy output.

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## How are Clean Ammonia Facilities Developed and Financed?

For the reasons mentioned above, developing clean hydrogen, and clean ammonia as a derivative, is a complex and capital intensive process that incorporates project development aspects of many different types of energy projects: power production from renewable energy (usually wind or solar), a transmission line to transport clean electrons, a hydrogen production facility, and, in the case of ammonia, an ammonia synthesis train along with ammonia storage and transportation infrastructure. Financing and building one of these projects is complicated; doing that for four or five projects that must interact sequentially and seamlessly can be challenging. This is often referred to as project-on-project risk.

To construct a clean hydrogen or ammonia facility involves the procurement of a lot of physical materials and the application of substantial human labor, and thus can be quite expensive. Developers must consider various structures and approaches to raise money to build these capital-intensive facilities. The most appropriate financing structure often depends on the characteristics of the developer, their cost of capital and the nature of the project.

For example:

- **Balance Sheet Financing:** Oil and gas supermajors and large public companies often have the financial strength to fund clean ammonia projects directly from their balance sheets. This approach reduces the need for external financing, minimizes financial market risks, and enables companies to maintain control over the project. However, balance sheet financing may tie up significant capital that could otherwise be used for other strategic initiatives.
- **Developer With Private Equity/Infrastructure Fund Backing JV:** Joint ventures (JVs) between project developers and private equity (PE) or infrastructure (Infra) funds have become a popular structure. PE and Infra funds provide the necessary financial capital while developers contribute their expertise in project management and execution. This approach allows both parties to share risks and benefits, leveraging the financial acumen of PE/Infra funds with the operational capabilities of developers. It is particularly beneficial in the early stages of project development, when a project

developer has industry expertise but lacks the funds to advance the project to a stage where it is ready for construction, and debt financing is not yet available.

- **Developer With Offtaker (including commodity traders) JV:** In this structure, project developers form JVs with offtakers, such as commodity traders or industrial users, who agree to purchase the ammonia or hydrogen produced. This arrangement is particularly important in the clean ammonia/hydrogen space, as clean ammonia/hydrogen costs more to produce than grey ammonia/hydrogen and that price differential is not yet fully reflected in the merchant ammonia/hydrogen market. This arrangement provides financial certainty for the project and ensures a steady revenue stream that is sufficient to cover the project's costs, making it easier to secure additional financing. The offtaker's involvement also aligns production with market demand, reducing the risk of oversupply.
- **Developer With Equipment Supplier and Offtaker JV:** This tripartite JV structure involves collaboration among developers, original equipment manufacturers (OEMs), and offtakers. Equipment suppliers bring in their technological expertise and may offer flexible payment terms or warranties, while offtakers guarantee the purchase of the end product. This structure facilitates risk-sharing and aligns incentives across the supply chain (but requires careful negotiation of the underlying arrangements to ensure that actual and potential conflicts of interests inherent in this structure are adequately addressed up-front).
- Project financing remains a widely used approach for clean ammonia facilities. It can be, and often is combined with the above structures, unless balance sheet financing for the entire project is available and will be more efficient than project financing. Project finance involves raising debt based on the project's expected cash flows and is usually undertaken in conjunction with the later stage of the project's development timeline and is closed just prior to construction of the project commencing.

A key challenge in project financing for clean ammonia/hydrogen projects is educating banks on the petrochemical-style risks and operating regimes, which differ significantly from those of traditional wind and solar projects. Ensuring favorable terms on offtake agreements (price, term, and percentage of fixed vs. merchant) is crucial for securing financing.

Construction risk is another critical consideration in clean ammonia projects. Coordinating multiple contractors and ensuring timely delivery of components is essential. Project finance lenders often prefer a single, lump-sum turnkey engineering, procurement and construction (EPC) agreement for the entire project to ensure a single point of responsibility (and liability) in case of issues with construction or performance. However, given the nascent state of the clean hydrogen/ammonia industry and the technology employed, few EPC contractors are currently willing to enter into such a contract (and those who are

willing, charge a very high premium for the shift in risk). Therefore, as discussed further below, effective risk allocation among multiple construction, technology and licensor companies will be required.

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## How are Clean Ammonia Facilities Constructed?

A clean ammonia facility comprises an interconnected set of projects, typically including units for renewable energy generation and transmission on one side (these concern the ‘electron’) and for electrolysis (for hydrogen production), air separation (for nitrogen production), synthesis, liquefaction and storage on the other side (these concern the ‘molecule’).

The integration of these various technologies is a significant challenge, particularly given the lack of meaningful reference projects. As we note above, the clean hydrogen/ammonia industry is relatively nascent and there is no settled procurement methodology. The NEOM Green Hydrogen Project in Saudi Arabia, purportedly the largest utility-scale commercial hydrogen facility in the world, was reportedly procured pursuant to a single EPC contract. This is an attractive option for stakeholders, as the contractor will ostensibly ‘wrap’ the technology, interface and other risks inherent in delivering complex and specialized process plant infrastructure. However, the disparate nature of the constituent technologies means that it will not always be possible (or desirable) to adopt this strategy in the global market.

It is far more likely, in our view, that projects will be procured on the same basis as the more complex petrochemicals plants, with developers entering into multiple EPC contracts with specialized contractors. The advantages of this approach include freedom for the developer to engage ‘best in class’ contractors for each unit and a probable reduction in overall cost, as the developer is not paying a premium to a third party to assume risk for delivery of the whole facility.

The contractual framework will contemplate tools to manage risk (and notably interface risk), such as co-ordination agreements (these set out the responsibilities of the different contractors) and mitigation plans which identify potential time and cost risks. However, the most practical mitigant is simply to engage experienced project managers, contractors and technology providers with a demonstrated history in delivery of the works and services for which they are being selected. One feature of petrochemicals projects, which is also relevant for clean ammonia, is that the various process licenses and technology agreements will need to include guarantees for the developer that the technologies work with each other and that they are legally permitted to be used together. Similarly, the technology providers will need to grant a degree of flexibility in the performance of their respective technologies which allows for deviations in performance by connecting technology provided by other suppliers. For example, if the output of one technology does not meet the

expected specification, the next technology in the process should be able to handle a degree of variance.

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## What Is the Market for Clean Ammonia?

Hydrogen as a fuel source has a number of downstream uses, some current and some potential, that include blending with natural gas for electricity production, as a direct fuel in vehicles through a fuel cell, residential heating and as an industrial application in heavy industries such as steel, concrete and petrochemical production. A developed market for clean hydrogen as a fuel source is still evolving, but it appears that the market for clean ammonia fuel will develop more rapidly. In particular, clean ammonia as a shipping fuel is emerging as the most likely clean hydrogen derivative fuel to be adopted at scale in the near term.

Traditionally, the maritime industry has relied on fossil fuels as its primary energy source to power shipping vessels. However, the carbon emissions associated with fossil fuel use, and the International Maritime Organization's goal to reduce greenhouse gas emissions, have spurred interest in green ammonia as a sustainable fuel source.

Ammonia's high energy density compared to hydrogen and methane, coupled with its carbon free emissions, make it a particularly attractive option. Ammonia is easier to liquify and requires less storage volume than other alternative green fuels, further enhancing its appeal. Several obstacles remain before the use of clean ammonia in the maritime industry can achieve widespread adoption. Most notably, existing ammonia transportation networks need to be expanded and modified so that ports have enough fuel at the right locations to allow ships to bunker effectively. Ammonia's toxicity also requires the use of new skills and the implementation of safety protocols so that ammonia can be safely integrated into fuel systems. Significant capital investments to support clean ammonia maritime infrastructure and development have already been made, with orders being placed for ammonia-powered combustion engines, and the world's first clean ammonia-powered container ship having come online in 2023.

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## How are Clean Ammonia/Hydrogen Developing and Where Do They Go From Here?

Given recent political developments in the US and high and/or unpredictable costs to develop purely green ammonia, market sentiment seems to be encouraging blue ammonia development in the near term. Should a more robust clean ammonia market develop, and applied technology prove capable

of decreasing and/or accurately quantifying production costs, increased green ammonia production would likely follow.

Another approach clean ammonia/hydrogen developers may take to mitigate risk and decrease capital expenditures is to develop new production and storage facilities at or near existing downstream energy infrastructure, such as refineries and chemical plants. This adjacency provides for the prospect of localized supply and offtake for feedstock and finished product, synergies on the use of industrial equipment and the ability to take advantage of the common features of a wider industrial campus such as laydown yards, transportation channels and overall market or port access. An example of this approach is seen through the partnership between Crossbridge Energy Partners and Everfuel to develop the HySynergy project to create clean hydrogen at Crossbridge's Fredericia refinery in Denmark.

The proponents and capital supporters of clean hydrogen and ammonia development are resourceful and dedicated. When there is a will, there is (usually) a way.

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