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From Fertilizer to Fuel: The Evolving Landscape of Ammonia Production

The emergence of green hydrogen production has had consequential effects on all its derivatives. Among these derivatives, ammonia has gained attention, particularly in the context of long-distance transportation of hydrogen. Indeed, its significantly higher boiling point renders it a preferred choice for shipping purposes, as highlighted in our previous article about the intercontinental transport of hydrogen. However, ammonia's role extends beyond being solely a hydrogen carrier. As an inorganic substance, ammonia presents itself as a potential substitute for fossil fuels whereby its versatility is becoming increasingly evident for a range of potential applications. Therefore, ammonia may assume a **crucial role in the future energy transition**. As discussions surrounding renewable energy sources intensify, ammonia's multifaceted utility positions it as a prospective contender in shaping the future landscape of energy utilization. In this latest article in our series on the hydrogen economy, we take a closer look at the role that ammonia – one of the most promising hydrogen derivates - might play in the green energy transition.

Geographical Dynamics of Ammonia Production: A Global Overview

An analysis of global ammonia production, as depicted in *Figure 1*, shows that the Asia-Pacific region (APAC), dominated by China, accounts for approximately 30% of worldwide ammonia output. Russia follows with an 11% share, while the United States contributes around 9% to the total global production. The significant concentration of ammonia production in these regions correlates amongst others with the availability of natural gas reserves and cheap production costs. Furthermore, a comparison of ammonia production and consumption volumes indicates that most ammonia is utilized within the regions where it is produced, leading to only about 10% of the total production being traded internationally (Bastien Bonnet-Cantalloube 2023).

Transitioning to Green Ammonia: Analyzing the Shift in Production Technologies and Economic Challenges

While ammonia's use as an inorganic gas can reduce CO2 emissions in some processes, its production itself is a significant source of greenhouse gas emissions. To meet emission reduction targets, these applications must shift towards green ammonia, produced using green hydrogen. An analysis of current ammonia production methods, as illustrated in Figure 2 on the left, indicates that around 55% of ammonia is directly synthesized from natural gas sources. Fossil-fuel based Carbon Capture and Utilization, or CCU, account for another 23% of production. Coal (without CCU) contributes approx. 21% of total ammonia production, and less than 1% is derived from oil-based sources. Notably, the share of production processes, which involve capturing and storing emitted greenhouse gases (Carbon Capture and Storage, or CCS) is negligible.

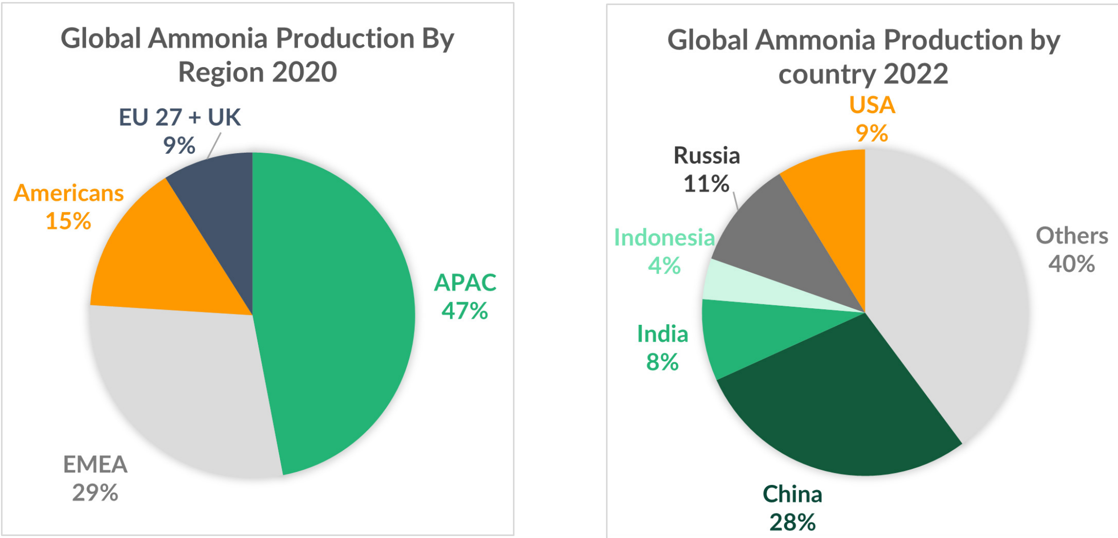

Figure 1: Global ammonia production by region (left) and country (right). The individual countries are assigned to either the Asia-Pacific (APAC), Europe-Middle-East-Africa (EMEA, excluding the EU and UK), Americans, or EU+UK region. Figures are reproduced from (Bastien Bonnet-Cantalloube 2023) and (Apodaca 2023).

The IEA's "Net Zero Emissions by 2050" Scenario outlines a trajectory for the ammonia industry to align with the global goal of reaching net zero emissions by 2050. This scenario, depicted in *Figure 2* on the right, foresees a shift towards more sustainable ammonia production technologies. Under this scenario, it is estimated that about 40% of ammonia will be produced using hydrogen from water electrolysis. CCS is also anticipated to grow to 22% in ammonia production from gas. Similarly nearly 21% of production will remain carbon-based but with CCU. Additional projected production methods include 7% from pyrolysis, 6% from gas processes, 3% from biomass, and just under 1% from coal with CCS.

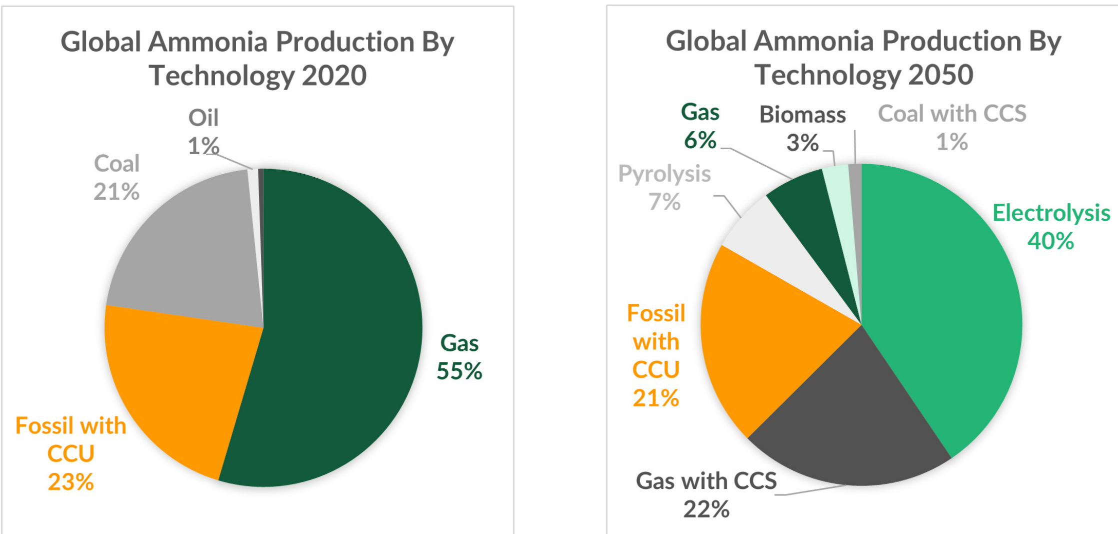

Figure 2: Evolution of the global Ammonia Production by Technology. Figures reproduced from (Sara Budinis, 2021).

Despite the forward-looking intention to solely employ low greenhouse gas emission manufacturing processes, it is imperative for companies to assess the cost competitiveness of producing green ammonia compared to grey/blue ammonia. The production cost of green ammonia primarily hinges on hydrogen costs, suggesting that **economic viability** relies on reducing green hydrogen production expenses. Yet, current indications suggest a difficulty in reducing hydrogen production costs in the near future. Consequently, especially during periods of low gas costs, green ammonia currently remains economically unfeasible, particularly in comparison to CO2-intensive processes. Even despite CO2 pricing initiatives, grey ammonia persists as the more cost-effective option.

Ammonia's Expanding Role: From Global Agriculture to Emerging Energy Solutions

Ammonia is one of the most extensively produced chemicals globally. Presently, its primary applications revolve around agriculture, the chemical industry, and various industrial sectors. Notably, the agricultural domain dominates ammonia consumption, predominantly due to its pivotal role as a primary feedstock for fertilizers, playing an indispensable role in maintaining global food supplies.

In *Figure 3*, the historical as well as forecasted global ammonia production is collated, as per the Net Zero Emission scenario according to the International Energy Agency (IEA), based on existing and announced policies. During the previous decade, it is shown that ammonia production has seen a consistent upward trend, culminating in approximately 185 million metric tons in 2021. Based on the IEA's predictions, demand for ammonia is expected to increase significantly towards 2050, with the majority of growth coming from anticipated uses as maritime fuel and electricity. For traditional uses as fertilizer and in industrial applications, limited growth is expected based on anticipated global population growth and economic expansion.

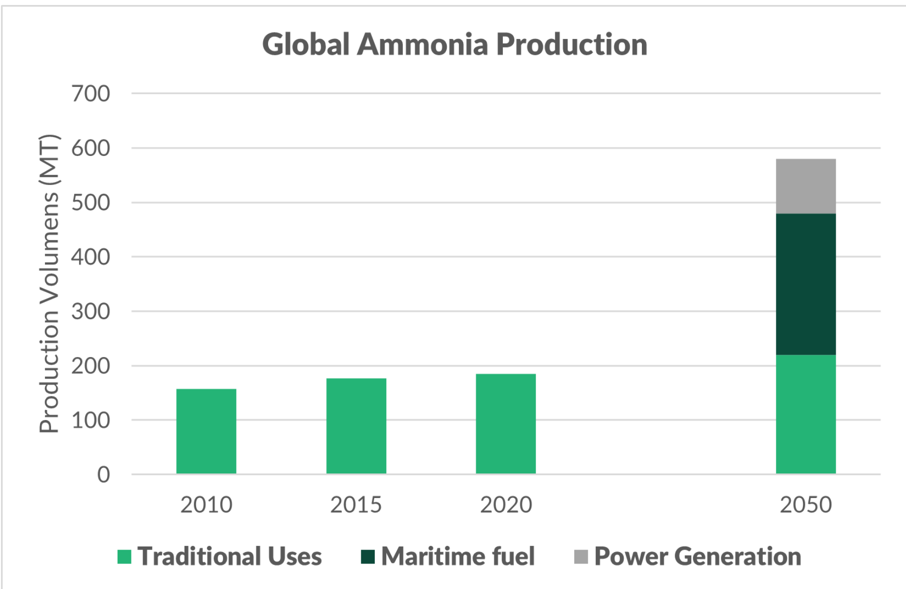

Figure 3: Global ammonia production in units of million metric tons for existing applications. The illustration combines the ammonia volume, produced until 2021, and the forecasted production volume. Figure reproduced from Sara Budinis (2021).

As shown in *Figure 3*, the potential applications of ammonia as an energy source are expanding across various sectors, presenting compelling alternatives to conventional energy sources. Notable among these applications include its utilization in steel factories as a substitute for fossil materials such as coal, coke, or methane. Research findings have indicated that ammonia presents a more cost-effective alternative to hydrogen usage in this context (Yan Ma June 2, 2023). Additionally, ammonia is increasingly being considered as a fuel in the maritime industry spurred by regulatory initiatives such as the Fit-for-55 program under the FEUM's framework. This is partly due to ammonia's ability to meet stringent environmental standards.

Ammonia's role as an energy carrier is another area of interest, particularly its conversion into electricity through various types of fuel cells, similar to hydrogen fuel cells. It also functions effectively as a hydrogen carrier, addressing the challenges associated with hydrogen's low boiling point. By converting hydrogen into ammonia, it offers a practical solution for storing and transporting energy. This versatility underscores ammonia's potential to contribute to a more sustainable and diverse energy landscape.

Conclusion

In conclusion, ammonia derived from green hydrogen stands as a promising energy alternative in various sectors due to its potential as an **alternative energy carrier and a substitute for traditional fossil fuels**. Projections indicate a significant surge in future ammonia demand, potentially reaching 600 million tons by 2050, demonstrating its expanding role across diverse applications like steel manufacturing and maritime fuel usage. While sustainable trajectories like the "Net Zero Emissions by 2050" Scenario offer a promising outlook, the need to reduce hydrogen production costs remains a significant barrier. Currently, the **economic viability** of green ammonia production, which relies on green hydrogen, faces challenges in competing with the more cost-effective grey ammonia. Overcoming these obstacles is crucial for leveraging green ammonia's potential as a pivotal element in a more sustainable and eco-friendly energy landscape.

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