Green Ammonia for Fertilizer Industry

Author

Dr. Muhammad Zeeshan Rafique

(For Renewables First)

Contents

1 Background....3

1.1 Uses of Ammonia....7

2 Situational Analysis of Pakistan....8

2.1 Current Status of the Ammonia Production in Pakistan....8

2.2 Major Players in Ammonia Production and consumption sector....8

2.2.1 Engro Fertilizers Limited:....9

2.2.2 Fauji Fertilizer Company (FFC):....9

2.3 Consumption Patterns....10

2.4 Stakeholder Engagement....11

3 Green Ammonia – Technical Analysis....12

3.1 Green Ammonia Production via Green hydrogen using electrolysis....12

3.2 Shifting Ammonia production....14

3.3 Benefits and Drawbacks for Green Ammonia Production....15

3.4 Cost of Green Ammonia....16

3.5 Green Ammonia – Supply Chain Pakistan....17

3.6 Solar Potential in Pakistan....18

4 SWOT Analysis for Green Ammonia Pakistan....20

Strengths (S):....21

4.1 Weaknesses (W):....21

4.2 Opportunities (O):....21

4.3 Threats (T):....22

5 SDG covered through Green Ammonia Implementation....23

Framework Green Ammonia – Pakistan....24

5.1 Processes....24

5.2 Production....25

5.3 Organizational Role 25
5.4 Government Policy 25
6 Government Policy on Fertilizer 26
6.1 Fertilizer policy 2001 26
6.2 GIDC 2015 26
6.3 Proposed Fertilizer Policy 26
6.3.1 Policy Measures 26
6.3.2 Implementation and Measuring 27
Bibliography 28
Annex – A 30
List of Stakeholders 30

Comprehensive Literature Review on Green Ammonia

1 Background

According to the UN, the world population is expected to reach 8.5 billion by 2030, with China and India to be the most populous regions [1]. The agricultural sector, responsible for food supply of the ever-rising population is secured by fertilizer uptake. The most abundantly used fertilizers are nitrogenous fertilizers synthesized from Ammonia. According statistics, Ammonia (NH_3) had a worldwide production of 235 million tons in 2019 and expected to increase to 289.83 million tons in 2030 [2]. About 70% of the ammonia produced globally is used for fertilizer production [3] .Ensuring access to cost-effective and readily available means of ammonia production is of utmost significance to maintain a stable and economically sustainable agricultural industry. The remaining 30% of the ammonia production is used in explosives, pharmaceuticals, refrigeration, cleaning products and many other industrial processes [4].In 2022, China was the world's leading producers of ammonia with 42 million metric ton followed by Russia, USA and India[5].

Ammonia production currently relies heavily on fossil fuels accounting for around 2% (8.6 EJ) of total final energy consumption. [6] Around 40% of this energy input is consumed as feedstock – the raw material inputs that supply a proportion of the hydrogen in the final ammonia product – with the rest consumed as process energy, mainly for generating heat. Just over 70% of ammonia is produced by natural gas-based steam reforming, while most of the remainder is via coal gasification [3].

Ammonia (NH_3) is an alkaline, colorless gas with pungent and suffocating odour. The boiling point for liquefied anhydrous ammonia is -33.3 C at atmospheric pressure [6]. After sulfuric acid, ammonia is the second most commonly produced chemical in the world [2]. Ammonia's compressible nature allows it compress easily and stays in liquid form above about 9 - 10 bar pressure at ambient temperature [7]. Haber-Bosch is the most conventional method for ammonia production. The Haber-

Bosch process has the disadvantages of high GHG emissions and energy consumption, mainly due to its high operating pressure and temperature [8].

Haber – Bosch process is widely used in ammonia production in large plants (1000 metric t/day approx.) accounting for 90% ammonia produced by using fossil fuels.[9].The Haber Bosch process is occurs at temperatures in the range of 400–500°C and pressure in the range of 150–300 bar, usually in the presence of an iron (Fe) based catalyst [10]. About 96% of the hydrogen (H_2) required for the production of ammonia via Haber-Bosch process is derived from fossil fuels [11]. The remaining 4% is generated from electricity which includes some indirect use of fossil fuels from coal or natural gas [12]. Approximately 3–5% of the natural gas produced globally is utilized for ammonia production via the Haber-Bosch process. The Steam Methane Reforming (SMR) process produces approximately 9–10 tons of carbon dioxide equivalent (CO_2eq) for each ton of hydrogen produced [11]. The SMR process derives 72% of hydrogen and 26% of hydrogen is obtained from coal for the production of ammonia [3]

The Haber-Bosch process has the drawback of high amounts of energy usage of over 30 GJ/ton NH_3 mainly due to its high pressure and temperature [14]. The global ammonia production is a highly energy intensive process that accounts for 2% of total energy consumption [10]. The hydrogen required for ammonia synthesis is acquired from natural gas and nitrogen from atmospheric air through compressors. The ammonia reaction via the Haber Bosch process is defined by:

$$3H_2 + N_2 = 2NH_3$$

As the global population continues to grow, there is a corresponding increase in the demand for agricultural crop production. The fertilizer uptake is necessary for food security mainly dependent on ammonia industry. However, the traditional ammonia production is not only energy-intensive but also generates significant greenhouse gas (GHG) emissions, **surpassing 2.16 tons of carbon dioxide (CO_2) per ton of ammonia (NH_3) produced**. The global imperative to transition of energy systems towards achieving net-zero emissions, possess a challenge towards hard to decarbonize industrial applications. Consequently, the rise is global population presses the need for greater ammonia production with significantly reduced emissions to align with carbon neutrality objective.

The IEA in 2020 projected the natural gas consumption sector wise providing a better overview of the usage in each sector.

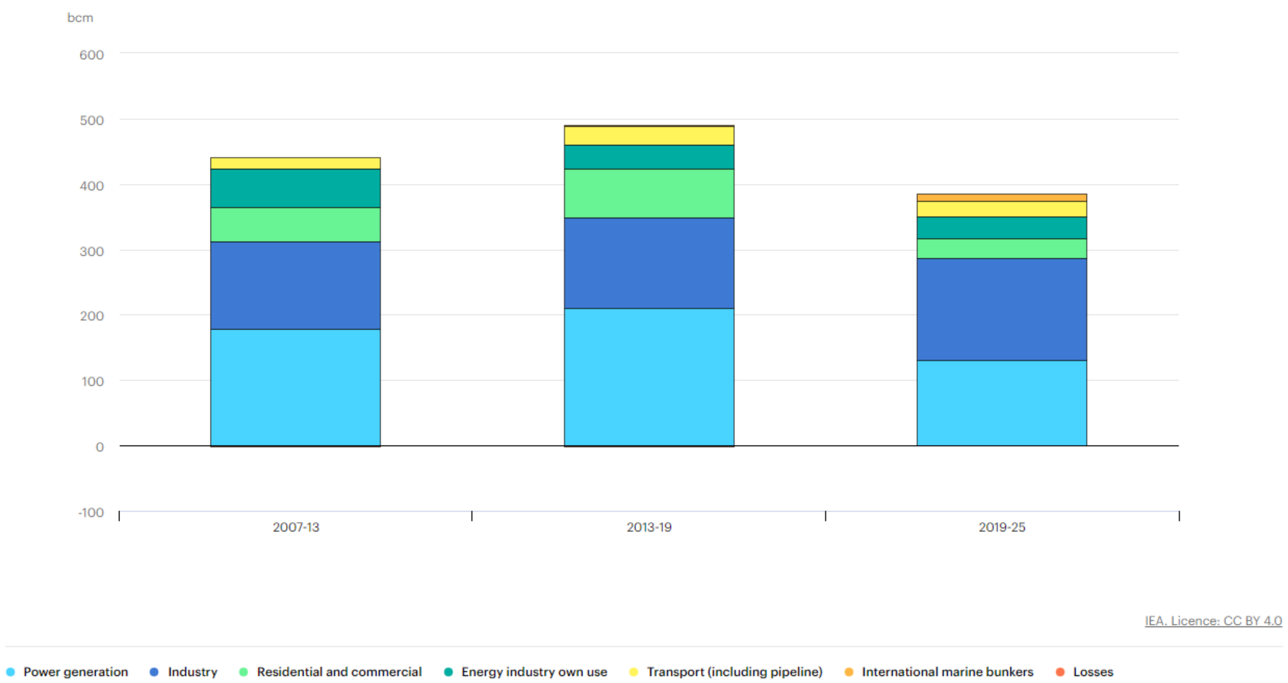


Figure 1 Global Natural Gas Demand (2019-25)

Natural gas has emerged as the second-largest contributor to global electricity generation, as a mid-term energy transition strategy to phase out coal. This transition is viewed favorably in terms of climate impact since it is assumed that gas generally produces fewer carbon dioxide emissions per unit of energy. However, the long-term net zero emission targets require a transition from gas to low-carbon alternatives like renewable energy. Pakistan's electricity production from natural gas is currently around 30 - 40 %.

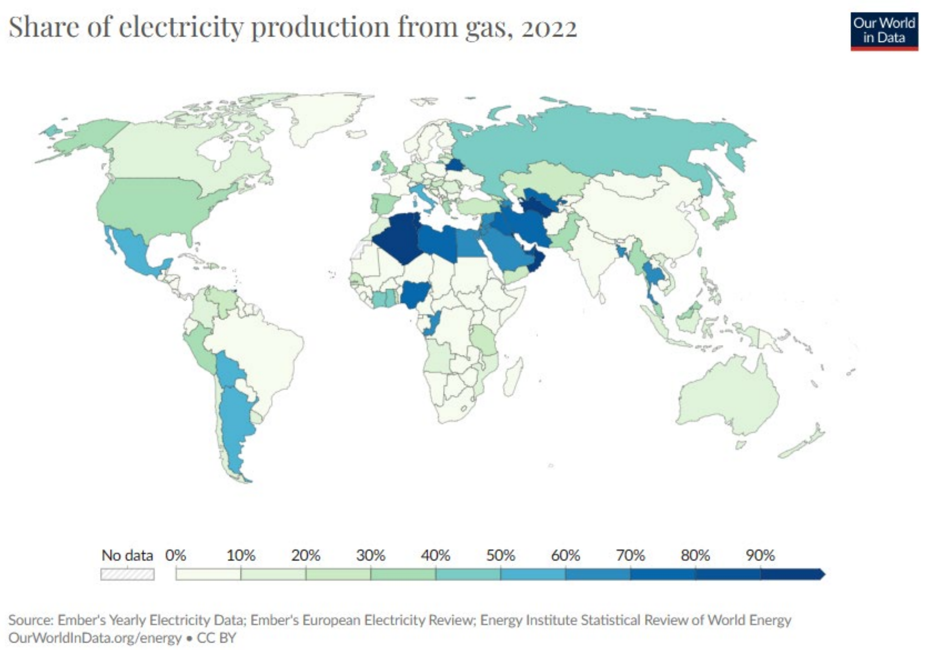


Figure 2 Electricity Generation from Natural Gas and RLNG

The primary energy consumption from gas across the world is shown in Figure-3. This represents gas production adjusted for trade (so, gas exports are subtracted and imports are added). (Note: 1TWh = 3412141633.13 cft of natural gas)

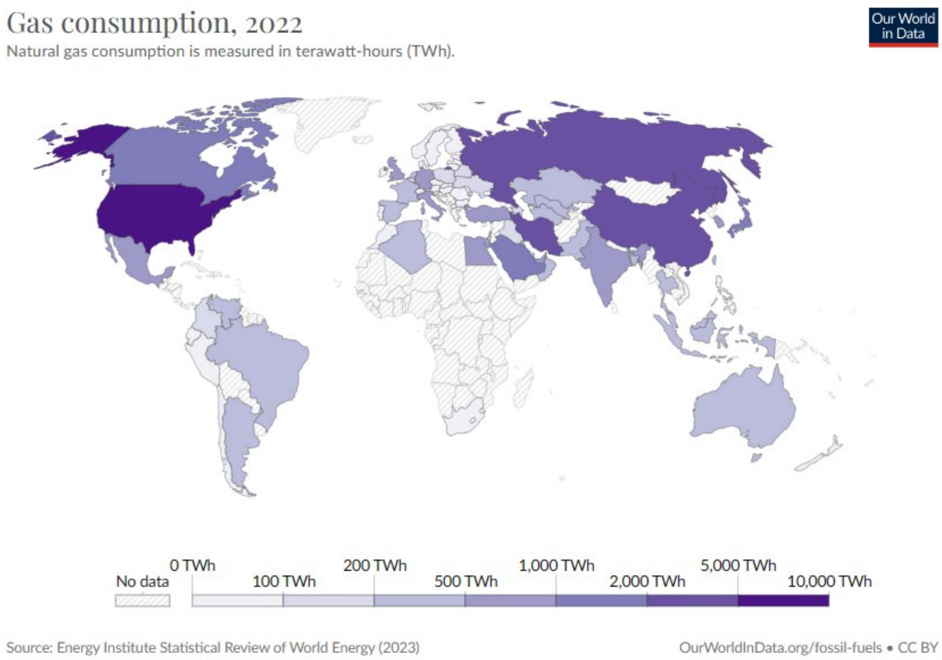


Figure 3 Consumption of Gas (World)

The Figure-4, highlights gas production data by country. To make this data comparable, the data is measured in terawatt-hours of energy. It's important to clarify that this data reflects gas production, not consumption. While many countries rely on gas as part of their energy supply, not all of them have the domestic reserves to produce it themselves.

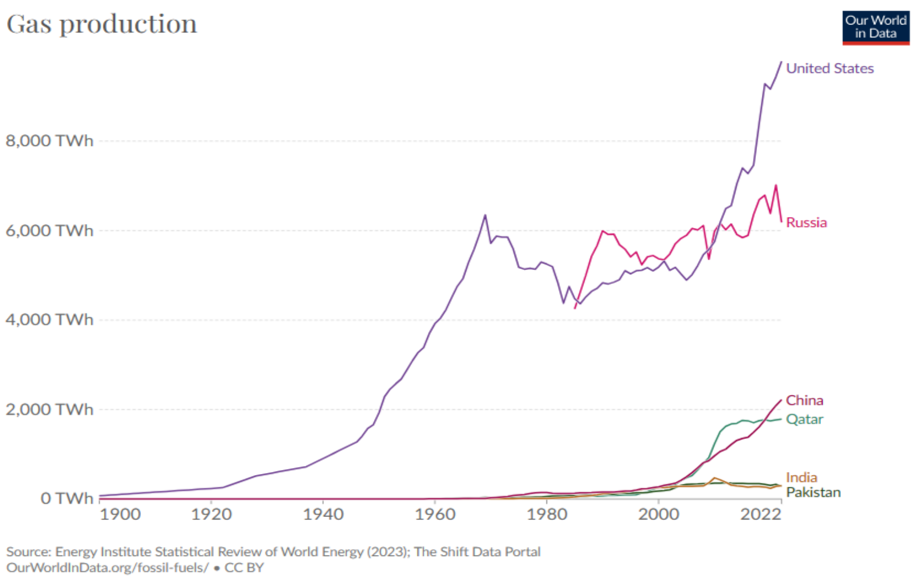


Figure 4 Production of gas (Country wise)

1.1 **Uses of Ammonia**

Anhydrous ammonia (NH_3) is a versatile compound with various industrial and agricultural applications. Liquefied ammonia can be stored and transported easily just like LNG.

1. Agricultural Fertilizer: Ammonia is a key component of nitrogen-based fertilizers. It provides a concentrated source of nitrogen that is essential for promoting plant growth and increasing crop yields.
2. Cold Storage as Refrigerant: It is used as a refrigerant in industrial refrigeration systems, including those in food processing, cold storage, and ice production. It has excellent thermodynamic properties, making it efficient for cooling applications.
3. Drinking Water Treatment: Ammonia is used in water treatment processes to adjust the pH levels of water and control the formation of chloramines. It helps ensure safe and clean drinking water.
4. Household Cleaning Products: Ammonia-based cleaning products, often diluted with water, are used for various household and industrial cleaning tasks. They are effective in removing grease, stains, and dirt.
5. Fabric Preparation: It is used in the textile industry for pH control and as a scouring agent to prepare fabric for dyeing.
6. Cheese Production: It is used in cheese production to adjust pH levels and aid in the curdling process.
7. Automotive Emissions Control: SCR systems in diesel vehicles and industrial applications use anhydrous ammonia as a reductant to reduce harmful nitrogen oxide (NO_x) emissions.
8. Pulp Bleaching: In the pulp and paper industry, anhydrous ammonia is used in the pulp bleaching process to adjust pH levels, contributing to the quality of the final paper product.
9. Metal Heat Treatment: Controlled atmosphere furnaces in metalworking use anhydrous ammonia as a coolant and protective atmosphere during heat treatment processes.
10. Fuel and Energy: While not a common application, anhydrous ammonia can be used as a fuel in internal combustion engines. It is also explored as a potential hydrogen carrier for energy storage and transportation.
11. Desulfurization: In flue gas desulfurization (FGD) systems, ammonia can be used to remove sulfur dioxide (SO_2) emissions from power plants.

Figure 5 Applications of Ammonia

2 Situational Analysis of Pakistan

2.1 Current Status of the Ammonia Production in Pakistan

The production of ammonia is reliant on imported and indigenous natural gas resources in Pakistan. Pakistan being an agrarian economy is dependent on agriculture. Fertilizers are the main essential requirement for the agricultural industry. According to PACRA [15], **Pakistan fulfils it's 84% of fertilizer requirement through local production** and meets the deficit through imports.

Ammonia production being an energy intensive process, requires resources for fuel stock as well as feedstock. All major contributors of ammonia producers use natural gas and have different supply networks; Engro-Mari, Fatima Fert. -Mari, FFC-Mari, Pak Arab-Mari, FFBL-SSGC.

The fertilizer industry is reliant on natural gas for steam methane reforming (SMR) process to extract hydrogen from natural gas, which requires a lot of energy along with the synthesis of ammonia.

2.2 Major Players in Ammonia Production and consumption sector

The major players in ammonia production are as follows;

Table 1 Major Ammonia Producers

Name	Location	Ammonia Production Process	Ammonia Production per day (mton)
Pak Arab Fertilizer (Fatima Group)	Multan	Haber Bosch Process Steam Methane Reforming	960
Agritech	Mianwali		600
Fauji Fertilizer (Plant 1)	Goth Machi, Sadiqabad		1000
Fauji Fertilizer (Plant 2)	Goth Machi, Sadiqabad		1100
Fauji Fertilizer (Plant 3) (PakSaudi Fetilizer Ltd.)	Mirpur Mathelo, Ghotki		1000
Engro Fertilizer	Daharki, Ghotki		1650
Fatima Fertilizer	Sheikhupura, Lahore		1500

2.2.1 Engro Fertilizers Limited:

Engro Fertilizers is one of the largest and most prominent players in the fertilizer industry in Pakistan. It is a subsidiary of Engro Corporation, a leading Pakistani conglomerate.

2.2.2 Fauji Fertilizer Company (FFC):

Fauji Fertilizer Company is another major player in the fertilizer industry in Pakistan. It is part of the Fauji Foundation, a well-known charitable trust in Pakistan.

2.2.3 Fatima Group:

Fatima Group is a diversified conglomerate with interests in various sectors, including the chemical and fertilizer industries. It is known for its significant presence in Pakistan's industrial landscape. Fatima Group is involved in ammonia production, which is integral to its fertilizer manufacturing operations.

These organizations are key players in Pakistan's ammonia production and fertilizer industry, and their activities have a direct impact on the agricultural sector, which is the backbone of the country's economy. They are instrumental in providing essential agricultural inputs to farmers, contributing to food security and economic growth in Pakistan.

2.3 Consumption Patterns

Ammonia being a high energy intensive process requires continuous supply of electricity as well as natural gas. The ammonia produced all over Pakistan is not enough to meet the demand country beholds. After consultations with some industry experts, it was concluded that a 1000 mton/day plant consumes 20 MW of energy. These ammonia plants have their separate steam turbines of capacities around 30% more than the required energy levels to provide with the electricity required by the plant, but is reliant on availability of natural gas from the government suppliers, which is the source of electricity generation as well as generation of hydrogen from natural gas.

As per consultations, it was found that ammonia plants vent out 1.4-1.6 mton of carbon dioxide per kg of scope 1 emissions during ammonia synthesis, which needs regulation. In total, **ammonia plants produce 2.9 mton carbon dioxide / ton ammonia produced**.

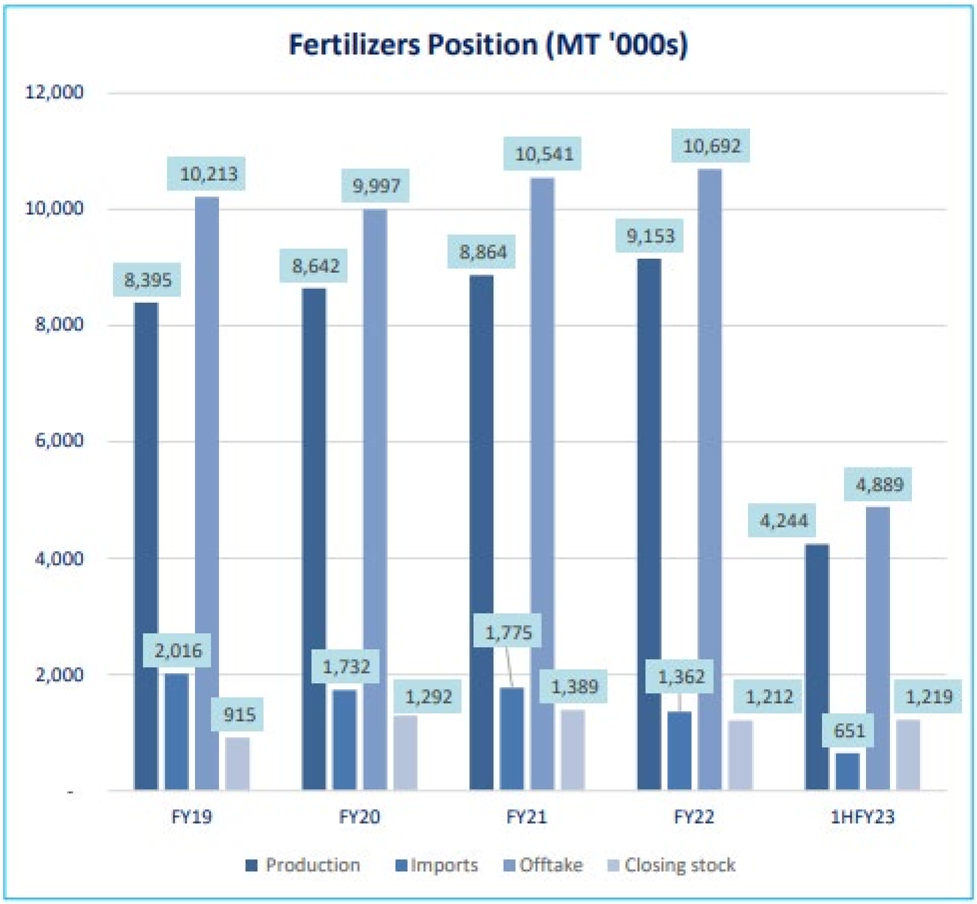


Figure 4 Supply and Demand Fertilizers Pakistan [15]

2.4 **Stakeholder Engagement**

A series of consultation were carried out with stakeholders, each possessing a wealth of expertise across diverse sectors. The fertilizer industry as one of the main stakeholder was consulted widely. The interviews were instrumental in obtaining a comprehensive understanding of the prevailing landscape within the fertilizer sector, as well as the intricacies of the ammonia production processes currently employed in Pakistan. The stakeholders' valuable perspectives and industry-specific knowledge have significantly contributed to the formulation of a holistic understanding of the subject matter under consideration. This stakeholder engagement was aimed at obtaining a more profound and comprehensive understanding of the measures necessary to mitigate the adverse environmental impacts associated with ammonia production and the concurrent depletion of natural resources within Pakistan.

Extensive consultations were undertaken with esteemed policy analysts to deliberate upon the government's ongoing initiatives aimed at providing substantive support to the fertilizer sector. The primary focus of these discussions was to ascertain the government's commitment to fostering the development of green technologies and facilitating the establishment of green ammonia plants within Pakistan. It was a collective effort to explore ways in which the nation could progress towards a net zero economy. Recognizing Pakistan's vulnerability to the impacts of global warming, the imperative to transition towards greener industrial processes and a more sustainable economy was thoroughly emphasized during these consultations. These dialogues underscored the urgency of aligning national policies with eco-friendly objectives to mitigate climate-related challenges and to promote long-term sustainability. The primary focus was to explore avenues for meeting the escalating demand for nitrogenous fertilizers through the adoption of green ammonia. This endeavor included strategies to support green ammonia production in various applications, thereby addressing the overarching objective of reducing import dependency and potentially contributing to the alleviation of Pakistan's circular debt.

3 Green Ammonia – Technical Analysis

Green ammonia is synthesized using carbon free alternatives. Conventional methods, known as "grey ammonia," are energy-intensive and heavily reliant on fossil fuels, contributing to greenhouse gas emissions and environmental degradation.

3.1 Green Ammonia Production via Green hydrogen using electrolysis

In this process, hydrogen is produced through the electrolysis of water by utilizing renewable energy [16]. For production of green ammonia, nitrogen is obtained from air using an air separation unit for Haber-Bosch process powered by sustainable electricity. The primary challenge in the production of green ammonia is its cost, with electricity expenses accounting for approximately 85% of the overall process. According to estimates from the International Energy Agency, the competitiveness of electrolysis hinges on electricity prices falling within the range of 1.5 to 5.0 USD cents per kilowatt-hour (kWh).

Over the past decade, regions endowed with abundant renewable energy resources have witnessed a significant decline in electricity costs. The utility-scale solar installations in Morocco, Chile, and Saudi Arabia have achieved remarkably low auction prices of 4.5, 3.2, and 2.3 USD cents/kWh, respectively. These developments suggest that water electrolysis may now be positioned to compete favorably with traditional steam methane reforming.[18]. Low electricity costs necessitate the competitiveness of green hydrogen, however ammonia's high technological readiness and developed transport infrastructure can play a crucial role in this supply chain.

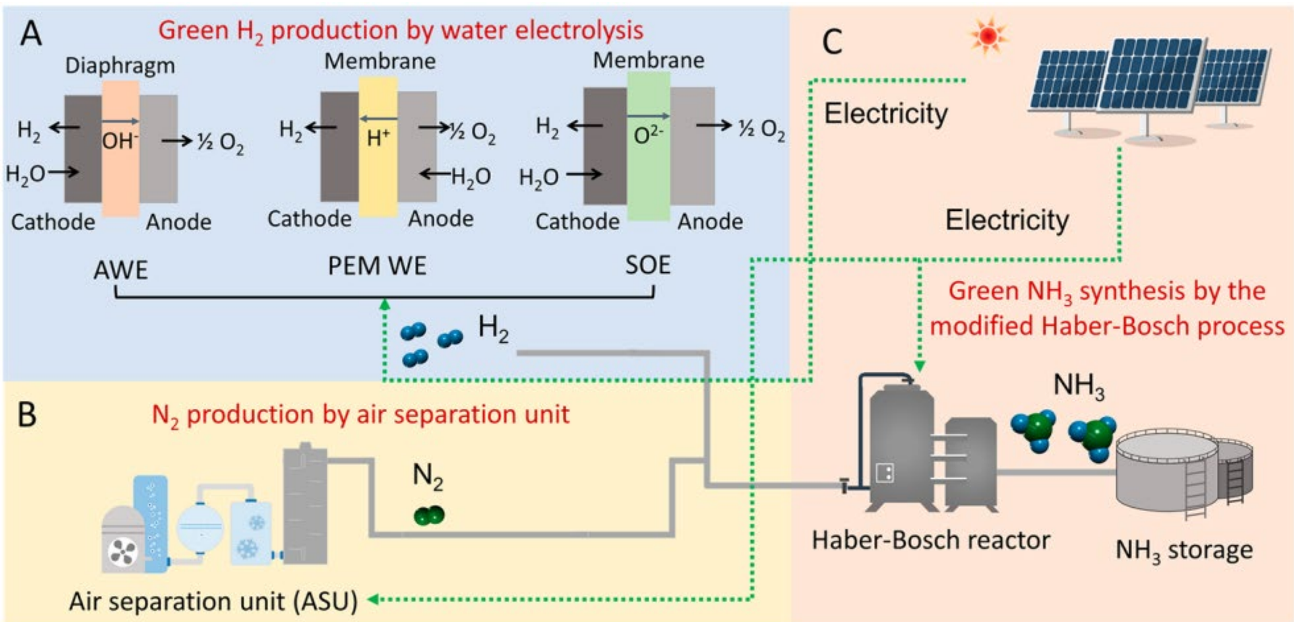


Figure 7 Green Ammonia Process

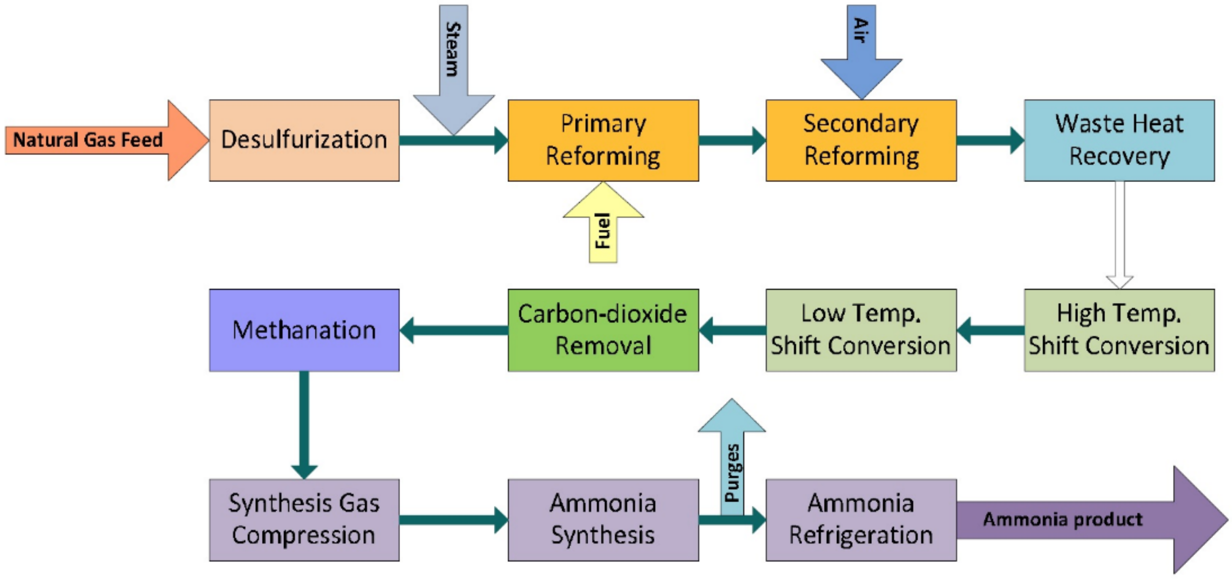


Figure 8 Grey Ammonia Process

Figure 9 shows that green ammonia production costs are already competitive with blue ammonia. However, costs vary widely across regions due to fuel and feedstock costs. The lowest electrolysis costs are found in locations with low renewable electricity costs, such as solar, high horizontal irradiance, and onshore wind.

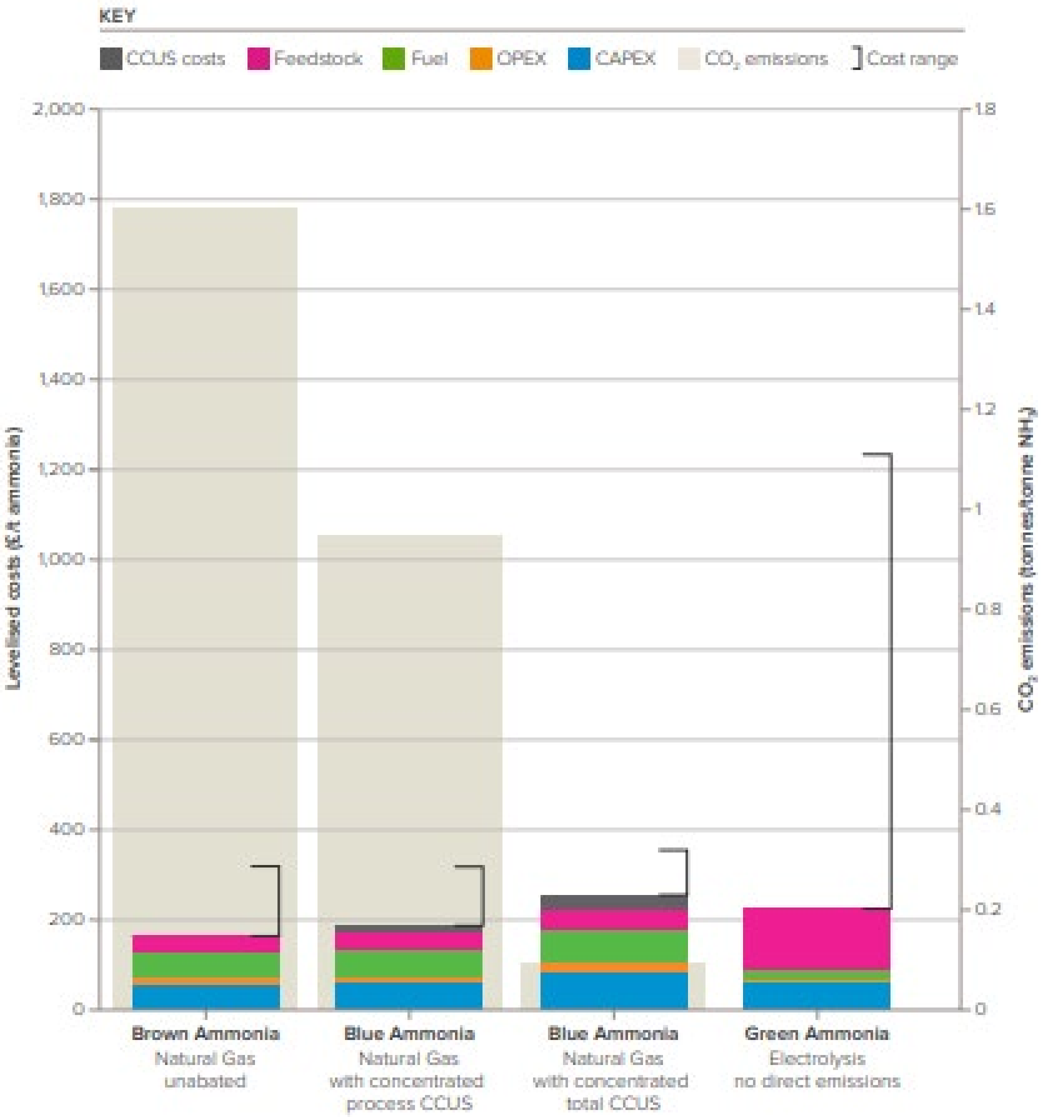


Figure 9 Aspects of Grey Blue and Green Ammonia

Green ammonia production significantly reduces carbon emissions by eliminating the need for fossil fuels. It can also serve as energy storage for renewable energy sources, a clean fuel for transportation and power generation. Additionally, it can be used as a sustainable fertilizer, reducing the carbon footprint of agriculture and minimizing the environmental impact of conventional ammonia-based fertilizers.

3.2 **Shifting Ammonia production**

Pakistan is currently facing economic challenges, marked by the devaluation of its currency and a heavy reliance on imports. The fertilizer sector, a critical component of the nation's economy, faces the necessity of embracing substantial and long-term investments to modernize its infrastructure. In the context of ammonia production, the industry recognizes three primary methods: grey, blue, and green ammonia. As illustrated in Figure-9 of this report, each of these production methods yields distinct environmental and economic impacts. Given the prevailing economic conditions and the imperative for sustainability, it is paramount for Pakistan's fertilizer industry to make informed decisions regarding its ammonia production processes, thereby ensuring a more resilient and economically viable future.

Grey ammonia production is conventionally reliant on natural gas as a feedstock to produce hydrogen for the Haber-Bosch Process. However, a notable alternative emerges in the form of blue ammonia, this process involves the capture of vented carbon dioxide emissions using specialized carbon capture units, with subsequent storage beneath the Earth's surface, often within geological formations. An exemplary case of this advanced technique is evident in Abu Dubai at Shah Gas Plant, which has the capacity of 2.3 MTPA to capture and store a significant amount of CO_2 emissions generated during the natural gas processing. The CCS plant at Shah Gas employs various technologies, including amine-based absorption, compression, and transportation of captured CO2 to injection wells for geological storage. These advancements underscore the potential of blue ammonia as a low carbon alternative in ammonia production processes [19]. The production of green ammonia represents a significant paradigm shift in ammonia synthesis, entailing the simultaneous generation of green hydrogen and green energy, which are pivotal for the ammonia manufacturing process. It is crucial to emphasize that this technological transition cannot be executed hastily; rather, it necessitates a concerted effort, drawing upon the collective technological expertise from diverse sectors. Collaboration among these sectors is indispensable to pursue the shared objective of fostering green ammonia production, thereby advancing sustainable and environmentally responsible practices within the industry.

3.3 Benefits and Drawbacks for Green Ammonia Production

Benefits	Drawbacks
Environmental Sustainability	
Reduced CO_2 Emissions No steam methane reforming process, producing carbon monoxide and carbon dioxide.	High capital investment Increased demand of renewable energy
Reduced Environmental Impact Using cleaner energy sources reduced the environmental impact on the environment	
Energy Transition	

Green Energy Goals The shortfall on electricity in Pakistan can be reduced by implementing renewable energy resources	The cost of green ammonia is very high as of now, with 10 – 40 % times the cost grey ammonia production but are expected to drop as the technology matures.
Job creation New plant setups and it operating will create direct and indirect jobs for the unemployed skill workers	
Resource optimization	
Fossil fuels Ammonia plants in Pakistan use natural gas as feedstock and fuel stock, after green ammonia implementation, the dependence on fossil fuels will be eliminated	Scarcity of water 1 ton hydrogen is produced by 9 litres of water. [20]
Economic	
Export Potential The production of green ammonia can serve as an exportable commodity, potentially improving Pakistan's balance of trade. As green ammonia plants have the capacity to produce 10,000-ton ammonia / day	Infrastructure Development Building the necessary infrastructure for green ammonia production and transportation can be time-consuming and costly.

3.4 Cost of Green Ammonia

Though the current cost of green ammonia is very high compared to traditional ammonia. However, this cost is expected to decrease as the renewable energy cost decreases. The current price of green ammonia is in the range of $ 700 – 1400 per tonne in regions with greater renewable energy potential. By 2030, it is expected to drop to $ 480 per tonne, and by 2050, to $ 310 per tonne. To make green ammonia competitive with grey ammonia, a carbon price reduction of around $150 per tonne of CO_2 is required. It is also estimated that, if the renewable electricity price is below $ 20 per megawatt-hour, green ammonia will be competitive with traditional ammonia.

Year	2020	2030	2040	2050
Low end ($/tonne)	720	475	380	310
High end ($/tonne)	1400	950	750	610

Figure 5 Cost of Green Ammonia [21]

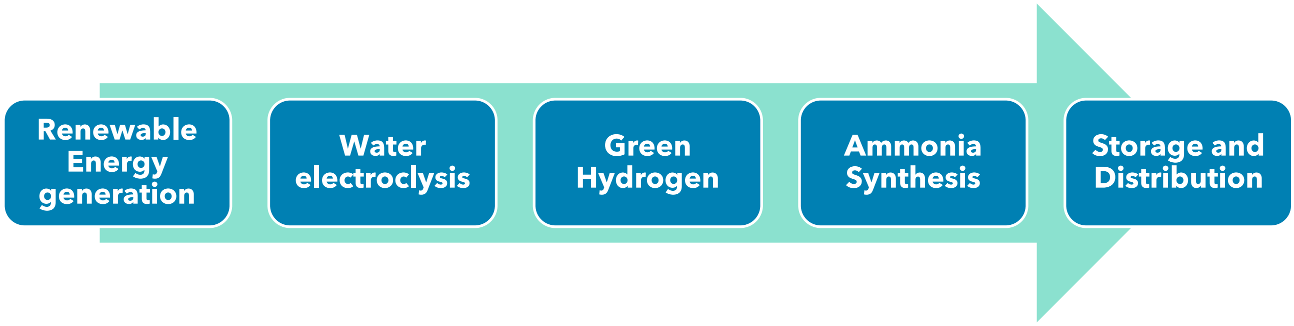
WEF suggests implementing a 50/50 green/blue ammonia supply in 2050 will require 850 billion USD in investments which will be largely invested in low emission power generation and for CO_2 transport and storage.

Low-emission production routes[1]	Estimated 2050 net-zero production[1]	Estimated infrastructure needs			
		Low-emission power generation		CO_2 transport and storage	
		Capacity required[3]	CapEx/unit	Capacity required	CapEx/unit
SMR with CCUS ATR with CCUS	48%			100 MTPA (2050-2075)[2]	$80-175 million/MTPA[4]
Grid-connected and dedicated VRE electrolysis	41%	447 GW	$1.9 billion/GW		
Biomass gasification	3%				
Methane pyrolysis	7%				
	Total investment required	$849 billion		$8-18 billion	

Figure 6 WEF proposition for 50/50, green/blue ammonia

3.5 Green Ammonia – Supply Chain Pakistan

The green ammonia supply chain depends on several factors:



Renewable Energy Generation: Pakistan can strategically exploit its renewable energy resources to overcome the electricity deficit. The supply and demand gap of electricity can be bridged by leveraging the renewable potential. Pakistan should establish a concrete roadmap for establishing local manufacturing industry for solar panel production, considering the nation's immense solar energy potential.

The country has high irradiance levels for optimum power generation from solar energy. The shift towards renewable energy aligns with global efforts to achieve climate neutrality and can stimulate economic growth through the creation of a domestic solar industry, generating employment and reducing import costs. Additionally, diversifying the energy mix and enhancing energy security for Pakistan's growing population and industries.

Water Electrolysis: The electrolysis process splits water molecules into hydrogen and oxygen gases. This technique uses electricity to drive the chemical reaction.

Green Hydrogen Production: The initial step to produce green ammonia entails the production of green hydrogen. This water electrolysis derived from renewable energy sources like wind, solar, or hydroelectric power produces green hydrogen.

Ammonia Synthesis: The green hydrogen is then combined with nitrogen to produce green ammonia through the Haber-Bosch process. The nitrogen is obtained by air through Air Separation Unit. This step requires specialized ammonia synthesis plants.

Storage and Distribution: Green ammonia is often stored and transported as a liquid or under pressure. Agricultural sector in Pakistan can benefit the most from green ammonia by producing Urea.

3.6 Solar Potential in Pakistan

Balochistan's abundant solar potential can be a pivotal factor in transforming the region's energy landscape. By harnessing solar power, not only can Balochistan meet its local energy needs sustainably, but it also opens up opportunities for green hydrogen and ammonia production. The high levels of solar irradiance provide a reliable source of energy to power electrolysers, which can split water into hydrogen and oxygen. This green hydrogen can then be used in the synthesis of green ammonia, a crucial component in various industries.

Balochistan's vast and sparsely populated terrain allows for the deployment of large-scale solar farms and renewable energy infrastructure. The surplus energy generated from these solar facilities can be dedicated to green hydrogen and ammonia production, offering an environmentally friendly and economically viable energy solution. By tapping into this solar potential, Balochistan can play a pivotal role in advancing Pakistan's renewable energy goals, reducing carbon emissions, and fostering sustainable development in the region.

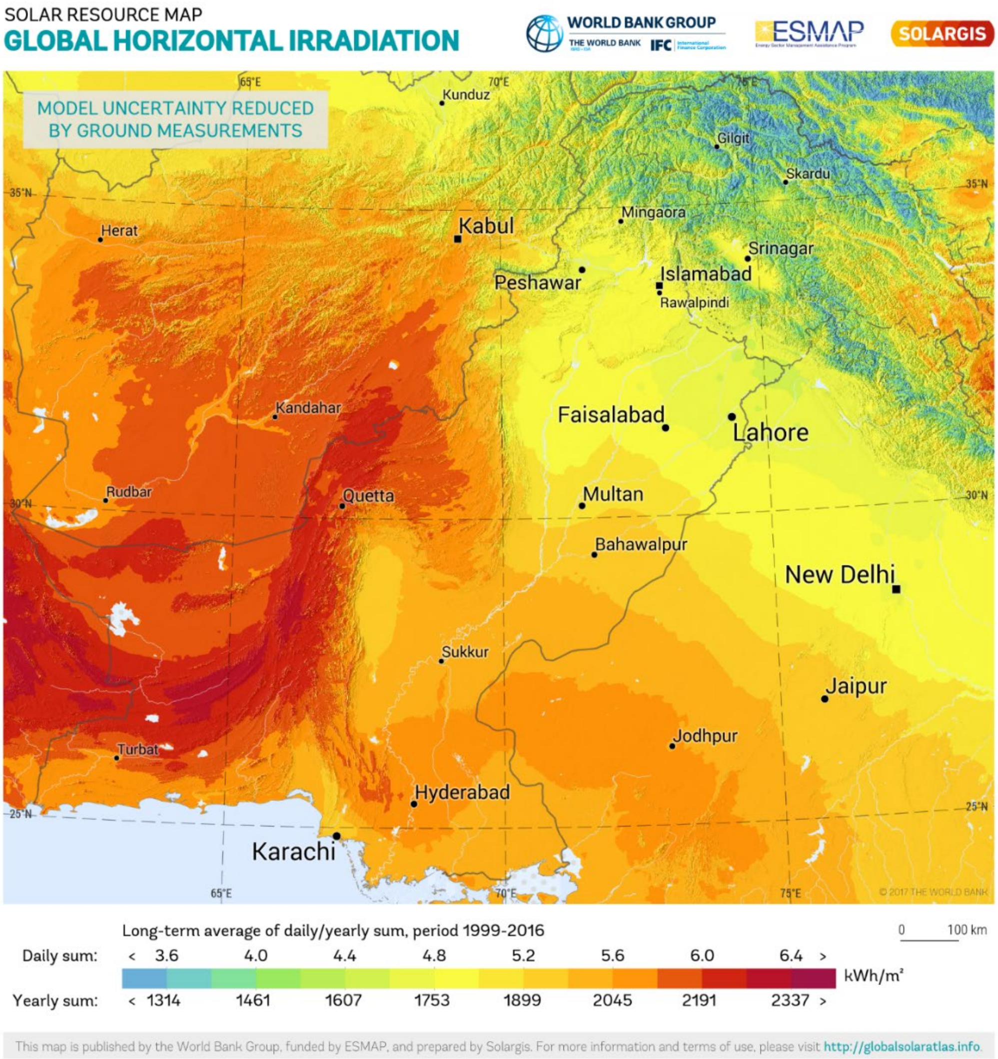


Figure 7 GHI Pakistan

4 SWOT Analysis for Green Ammonia Pakistan

Strengths (S):

1. **Abundant Renewable Resources**: Pakistan has significant potential for renewable energy sources, particularly solar and wind power, which can be harnessed for green ammonia production.
2. **Environmental Benefits**: Green ammonia production aligns with Pakistan's efforts to reduce carbon emissions and combat climate change, contributing to the country's environmental goals.
3. **Agriculture Dominance**: Pakistan's agriculture sector is one of the largest contributors to its economy, and green ammonia can offer sustainable and low-carbon fertilizer options, supporting agricultural growth.
4. **Government Support**: The Pakistani government has shown interest in renewable energy and sustainable practices, potentially offering policy incentives and support for green ammonia projects.

4.1 Weaknesses (W):

1. **Infrastructure Development**: The development of infrastructure for green ammonia production, storage, and transportation would require significant investments and time.
2. **Cost Challenges**: Initial investments for green ammonia production facilities can be high, and the cost-effectiveness compared to traditional ammonia production may be a barrier.
3. **Technological Know-How**: Developing the necessary expertise and technology for green ammonia production may pose challenges, requiring training and knowledge transfer.
4. **Incompetence from Government to provide proper guidelines:** The instability in governments does not allow them to provide a proper roadmap for the fertilizer industry to follow sustainable practices across the fertilizer sector

4.2 Opportunities (O):

1. **Energy Transition**: Pakistan's growing interest in renewable energy sources and energy transition creates opportunities for green ammonia as an energy carrier and energy storage medium.
2. **Agricultural Sustainability**: With a focus on sustainable agriculture, green ammonia can play a pivotal role in providing eco-friendly fertilizers and addressing environmental concerns related to traditional fertilizers.

3. **Global Export**: Pakistan can potentially export green ammonia to international markets where sustainable and low-carbon products are in demand.

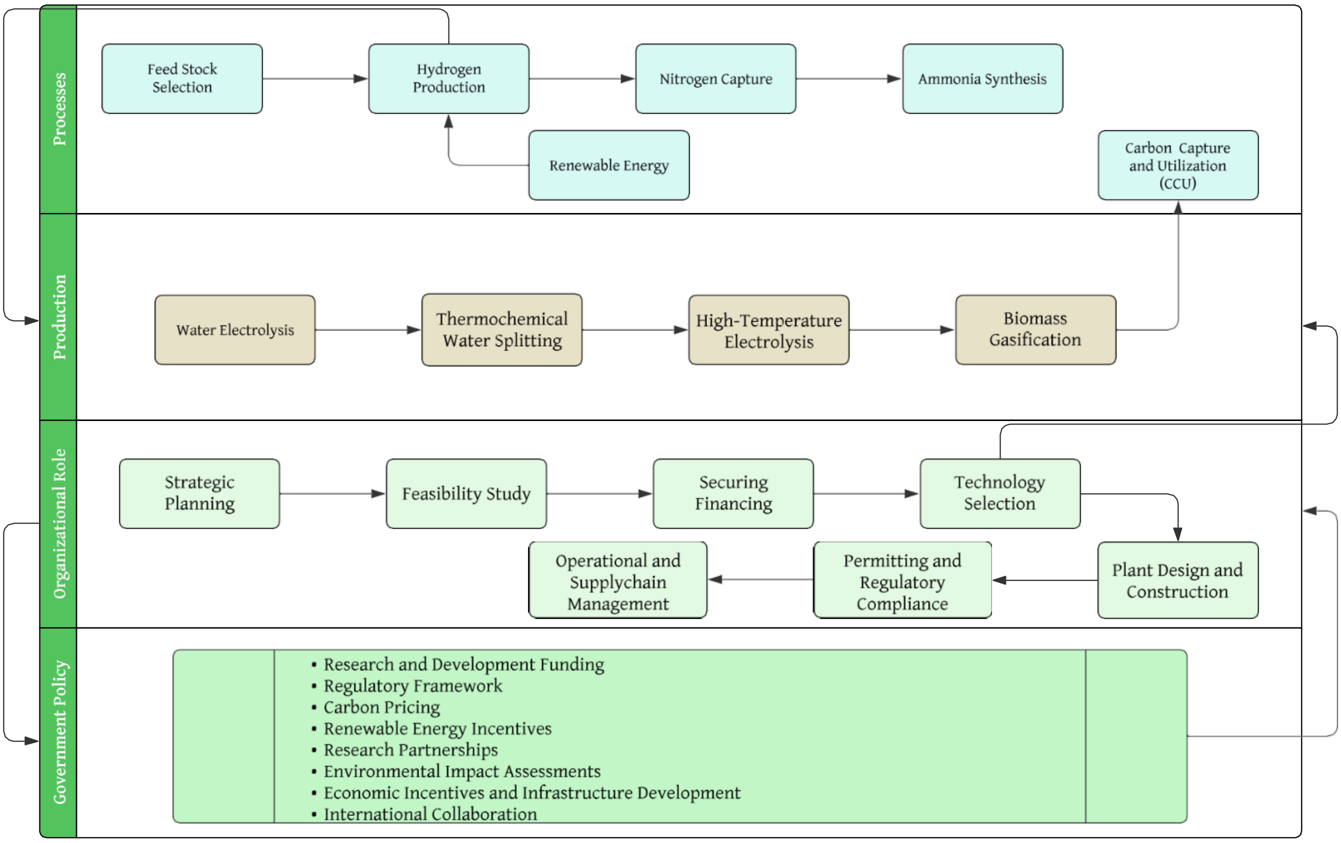
4.3 Threats (T):

1. **Cost Competitiveness**: Traditional ammonia production methods may remain cost-competitive, posing a threat to the adoption of green ammonia, especially if subsidies or incentives for traditional ammonia production continue.
2. **Regulatory Hurdles**: Adhering to international standards and certifications for green ammonia production and transportation can be challenging and time-consuming.
3. **Market Volatility**: Fluctuations in energy prices and market dynamics can impact the financial viability of green ammonia projects.
4. **Infrastructure Gaps**: Lack of infrastructure for renewable energy and green ammonia can hinder its development and distribution.
5. **Technological Risks**: Ongoing research and development are necessary to improve the efficiency and cost-effectiveness of green ammonia production, with risks of technological setbacks.

In Pakistan, green ammonia has the potential to align with the country's renewable energy goals, support sustainable agriculture, and contribute to environmental objectives. However, addressing infrastructure challenges, ensuring cost competitiveness, and navigating regulatory requirements will be key factors in its successful implementation and growth. Additionally, international collaboration and access to global markets may provide opportunities for Pakistan's green ammonia industry.

5 SDG covered through Green Ammonia Implementation

Framework Green Ammonia – Pakistan



Green ammonia production is a sustainable method for producing ammonia (NH_3) for fertilizers, as it uses renewable energy sources and carbon capture technologies, aiming to eliminate the carbon emissions associated with use of fossil fuels.

5.1 **Processes**

Green hydrogen production is a crucial step in green ammonia production, typically achieved through water electrolysis, where water is split into hydrogen and oxygen using electricity from renewable sources. Optimizing Haber-Bosch process can reduce energy consumption and emissions, making it a viable option for green ammonia production. Carbon capture and utilization (CCU) technologies minimize carbon emissions by capturing and utilizing the carbon dioxide produced during the process. Ammonia purification removes impurities and unreacted gases to obtain high-purity ammonia suitable for fertilizer production, typically through distillation or other separation techniques.

5.2 **Production**

Water electrolysis is a process that splits water into hydrogen and oxygen using an electrolysis cell with a proton-exchange or anion exchange membrane. Alkaline electrolysis uses an alkaline electrolyte, like potassium hydroxide, but is generally less efficient. High-temperature electrolysis uses high-temperature electrolysis cells and is often coupled with concentrated solar power for increased efficiency. Biomass gasification produces hydrogen as a byproduct from heating organic materials, which can be separated through purification methods. Biological hydrogen production is also being researched, with microorganisms like bacteria and algae producing hydrogen through processes like fermentation or photosynthesis. Pyrolysis involves heating organic materials without oxygen to produce a mixture of gases, including hydrogen. Chemical processes like water-gas shift reactions generate hydrogen using carbon-containing feedstock, necessitating carbon capture and utilization (CCU) to ensure environmental sustainability.

5.3 **Organizational Role**

The strategic planning for a green ammonia production involves market analysis, regulatory compliance, feasibility study, financing, technology selection, plant design and engineering, permitting, construction and commissioning, operational management, supply chain management, environmental stewardship, quality assurance and certification, community engagement, research and development, monitoring and reporting, sustainability and innovation, and risk management. The plan must consider the demand for green ammonia in the fertilizer industry, research and stay updated on environmental regulations and incentives. The plan must also ensure compliance with environmental and safety regulations, establishing reliable supply chains, implement sustainable practices, obtain necessary certifications, and engage with local communities.

5.4 **Government Policy**

Governments can support green ammonia production technologies through grants, subsidies, and tax incentives. They should establish clear regulations and standards, incentivize the use of cleaner, more sustainable technologies, implement carbon pricing mechanisms, and provide incentives for renewable energy sources. Governments can also facilitate research partnerships, promote market access and certification, invest in infrastructure, conduct rigorous environmental impact assessments, and offer financial incentives to companies transitioning to green ammonia production. International collaboration on standards and technology transfer can facilitate global adoption and ensure a level playing field for the industry. These measures can help reduce emissions, lower costs, and promote sustainability in the fertilizer industry.

6 Government Policy on Fertilizer

6.1 Fertilizer policy 2001

The Government of Pakistan implemented a Fertilizer Policy in 2001 to encourage investment in the fertilizer industry. The policy aimed to maintain reasonable fertilizer prices for farmers and promote domestic production. It included provisions for existing plants, setting escalation rates for feed gas prices. New investors were offered competitive gas prices based on Middle Eastern rates, with a 10% discount for the first 10 years. Fuel gas prices remained in line with other industrial consumers. The policy also supported the import and local manufacture of plants and allowed the relocation of second-hand equipment. Expansion projects were treated similarly to new investments. The policy emphasized equal treatment for all fertilizer producers, whether domestic or foreign, public or private.

6.2 GIDC 2015

The Gas Infrastructure Development Cess (GIDC) Act of 2015 in Pakistan was introduced to levy a cess (tax) on natural gas consumers for the development of gas infrastructure. Under this act, various sectors, including industrial, commercial, and domestic consumers, were required to pay the GIDC to fund gas infrastructure projects. The act aimed to generate revenue for the expansion and maintenance of gas infrastructure in the country. However, it faced legal challenges and controversies due to its implementation and the high rates imposed on consumers. The act has undergone amendments and legal disputes, leading to discussions about its fairness and compliance with legal standards in Pakistan.

6.3 Proposed Fertilizer Policy

The Green Ammonia Policy for the Fertilizer Industry is designed to encourage and facilitate the transition from conventional "grey" ammonia production to environmentally sustainable "green" ammonia production methods within Pakistan's fertilizer industry. This policy should aim to incentivize and promote the adoption of renewable energy technologies to reduce environmental impacts and contribute to a more sustainable and green economy.

6.3.1 Policy Measures

6.3.1.1 Incentive Frameworks

- Provide financial incentives, tax breaks, and subsidies for fertilizer companies investing in green ammonia production technologies.
- Offer preferential tariffs on utilities for green ammonia plants.

- Establish a Green Ammonia Fund to support research, development, and adoption of green technologies. This fund can be created by cutting the profit margin of fertilizer companies from 34% to 25% and dedicate the amount to green ammonia fund.

6.3.1.2 Regulatory Frameworks

- Set emissions reduction targets and standards for ammonia production facilities.
- Implement a carbon pricing mechanism, such as a carbon tax or cap-and-trade system, to incentivize emissions reduction.
- Establish reporting and verification mechanisms to track and measure greenhouse gas emissions.

6.3.1.3 Infrastructural Development

- Invest in infrastructure development, such as ammonia storage and transportation facilities, to support the growth of green ammonia production.
- Facilitate the establishment of green ammonia hubs to enhance production efficiency.

6.3.2 Implementation and Measuring

- Establish a dedicated regulatory authority responsible for overseeing the implementation of this policy, setting benchmarks, and monitoring compliance.
- Conduct periodic reviews and evaluations of the policy's effectiveness in promoting green ammonia production and reducing environmental impacts.
- Encourage stakeholder engagement and collaboration among government bodies, industry players, academia, and civil society to ensure policy alignment and successful implementation.

Bibliography

1. Nations U. Population | United Nations. Accessed September 7, 2023. https://www.un.org/en/global-issues/population
2. Soloveichik G. Future of ammonia production: improvement of Haber-Bosch process or electrochemical synthesis. In: *The 14th Annual NH3 Fuel Conference*. ; 2017.
3. Energy Agency I. Ammonia Technology Roadmap Towards more sustainable nitrogen fertiliser production. Accessed September 7, 2023. www.iea.org/t&c/
4. Giddey S, Badwal SPS, Kulkarni A. Review of electrochemical ammonia production technologies and materials. *Int J Hydrogen Energy*. 2013;38(34):14576-14594. doi:10.1016/j.ijhydene.2013.09.054
5. Global ammonia production by country 2022 | Statista. Accessed September 7, 2023. https://www.statista.com/statistics/1266244/global-ammonia-production-by-country/
6. Appl M. Ammonia: Priciples & industrial practice. Published online 1999.
7. Giddey S, Badwal SPS, Munnings C, Dolan M. Ammonia as a renewable energy transportation media. *ACS Sustain Chem Eng*. 2017;5(11):10231-10239.
8. Modak JM. Haber process for ammonia synthesis. *Resonance*. 2011;16(12):1159-1167. doi:10.1007/S12045-011-0130-0/METRICS
9. Guerra CF, Reyes-Bozo L, Vyhmeister E, Caparrós MJ, Salazar JL, Clemente-Jul C. Technical-economic analysis for a green ammonia production plant in Chile and its subsequent transport to Japan. *Renew Energy*. 2020;157:404-414.
10. Wang L, Xia M, Wang H, et al. Greening ammonia toward the solar ammonia refinery. *Joule*. 2018;2(6):1055-1074.
11. Parkinson B, Tabatabaei M, Upham DC, et al. Hydrogen production using methane: Techno-economics of decarbonizing fuels and chemicals. *Int J Hydrogen Energy*. 2018;43(5):2540-2555.
12. Matzen MJ, Alhajji MH, Demirel Y. Technoeconomics and sustainability of renewable methanol and ammonia productions using wind power-based hydrogen. Published online 2015.
13. Heffer P, Prud'homme M. Global nitrogen fertilizer demand and supply: Trend, current level

and outlook. In: *International Nitrogen Initiative Conference. Melbourne, Australia*. ; 2016.

14. Ghavam S, Vahdati M, Wilson IAG, Styring P. Sustainable Ammonia Production Processes. *Front Energy Res*. 2021;9(March):1-19. doi:10.3389/fenrg.2021.580808

15. Fertilizers Sector Study. Published online 2023.

16. Thomas H. Options for producing low-carbon hydrogen at scale. Published online 2018.

17. Executive Summary – Ammonia Technology Roadmap – Analysis - IEA. Accessed September 7, 2023. https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary

18. Navas-Anguita Z, García-Gusano D, Dufour J, Iribarren D. Revisiting the role of steam methane reforming with CO2 capture and storage for long-term hydrogen production. *Sci Total Environ*. 2021;771:145432.

19. Orca: The World's Largest Carbon Capture Plant located in Iceland. Accessed September 11, 2023. https://www.inspiredbyiceland.com/business/worlds-largest-carbon-capture-plant-opens-in-iceland

20. Cong L, Yu Z, Liu F, Huang W. Electrochemical synthesis of ammonia from N2 and H2O using a typical non-noble metal carbon-based catalyst under ambient conditions. *Catal Sci Technol*. 2019;9(5):1208-1214. doi:10.1039/C8CY02316F

21. IRENA. Accessed September 11, 2023. https://www.irena.org/-/media/files/irena/agency/publication/2018/jan/irena_2017_power_costs_2018.pdf

Annex – A

List of Stakeholders

Scope of Stakeholder	Number of Stakeholders	Expertise
Fertilizer Industry	2	Working experience for fertilizer industry for past 10 years
Ph.D. Professor	1	Sustainability
Ph.D. Student	1	Industrial Engineer
Policy Analyst	2	Law making and enforcement
M.Sc.	2	Research & Report Compilation