CPD Working Paper 154

Advanced Technologies for Clean Energy in IEPMP

What can be the Financial, Social, and Environmental Costs of These Technologies?

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CENTRE FOR POLICY DIALOGUE

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The present paper titled ***Advanced Technologies for Clean Energy in IEPMP: What can be the Financial, Social, and Environmental Costs of These Technologies?*** has been prepared by *Dr Khondaker Golam Moazzem*, Research Director, CPD (moazzem@cpd.org.bd); Ms Helen Mashiyat Preoty, Senior Research Associate, CPD (preoty@cpd.org.bd); and *Mr Mashfiq Ahsan Hridoy*, Research Associate, CPD (mashfiq@cpd.org.bd).

Series Editor: *Dr Fahmida Khatun*, Executive Director, CPD.

Executive Summary

The Integrated Energy and Power Master Plan (IEPMP) 2023 lays out the plan to adapt hydrogen and ammonia along with carbon capture units and nuclear as clean energy and attain the 40 per cent clean energy goal by 2041. Such technologies are comparatively new and the efficiency level of reducing emissions has not been tested appropriately. Theoretically, fossil hydrogen, known as grey and blue hydrogen, and fossil ammonia, known as grey and blue ammonia have not yet proved to be efficient for carbon emission reduction. Hence, the environmental and social impacts of these technologies along with the financial viability in Bangladesh must be assessed. This paper tries to estimate the environmental impact, financial viability, and social consequences of hydrogen and ammonia in the context of Bangladesh.

The findings show that in Bangladesh, the emission reduction by cofiring hydrogen and ammonia with gas and coal is negligible. Only 1 per cent of the total emission from gas-fired power plants will be reduced by co-firing it with hydrogen. On the other hand, the cost of hydrogen co-fired power generation will be BDT 5673.22 crore in 2041 for the generation capacity of 1600 MW. Similarly, in the case of ammonia, co-firing with coal, the cost of deployment is much higher than the emission reduction rate. The total investment to deploy to generate 1300 MW from the ammonia will be BDT 3685.37 crore in 2030. The financial cost exceeds the environmental benefit, indicating that adapting ammonia and hydrogen co-fired power generation is a false solution for the energy transition in Bangladesh. Additionally, it will also create an additional financial burden on the existing one further depriving the other sectors in need.

Instead, financial resources should be used to generate electricity from traditional renewable energy sources. With the equivalent amount of total investment for hydrogen and ammonia, 29,139 MW of solar energy and 821 MW of wind energy can be deployed. A total of 29,960 MW from renewable energy can easily fulfil the 40 per cent (24,000 MW) renewable energy target of Bangladesh. The renewable energy deployment can end up generating 58,123 new employments. Moreover, the stance on advanced technologies mentioned in the IEPMP needs to be reassessed and revised accordingly. In lieu of going for false solutions by adapting hydrogen and ammonia co-firing, the focus should be on deploying renewable energy in the medium to short-term.

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Table of Contents

List of Tables, Table Technology Setting, Figures and Annexes

List of Table Technology Setting and Annexes

Acronyms

IEPMP	Integrated Energy and Power Master Plan
MoPEMR	Ministry of Power Energy and Mineral Resources
CCS	Carbon Capture and Storage
CCGT	Combined Cycle Gas Turbine
BDT	Bangladeshi Taka
EOR	Enhanced Oil Recovery
BECCS	Bioenergy with Carbon Capture and Storage
SMR	Small Modular Reactor
LOHC	Liquid Organic Hydrogen Carrier
KWh	Kilowatt-hour
toe	Tonnes of Oil Equivalent
CO_2	Carbon Dioxide
NH3	Ammonia
H2	Hydrogen

1. INTRODUCTION

In November 2023, the new Integrated Energy and Power Master Plan (IEPMP) 2023 was approved by the Ministry of Power Energy and Mineral Resources (MoPEMR). The plan lays out the roadmap of achieving 40 per cent of the power generation from so-called 'clean energy' by 2041. However, the final plan stated 40 per cent of 'clean energy' sources as 'advanced technologies' such as carbon capture and storage (CCS), ammonia co-firing and single firing, and hydrogen co-firing and single firing, as a solution. These 'advanced technologies' that IEPMP advocates are comparatively new and most of the countries have not yet conducted testing on the extent to which they effectively reduce carbon emissions. A few developed and developing countries such as Japan, China, Germany, and Spain have adopted hydrogen and ammonia for power generation not so while ago. Furthermore, these countries have adopted renewable fuel cells meaning green hydrogen and ammonia for power generation, which have been causing quite a deep cut in the pockets of these developed countries. Countries like Germany have expressed their concerns regarding the subsidy required to use hydrogen and ammonia as energy sources. Hence, the so-called advanced technologies that are being considered for power generation in Bangladesh are not out of the question.

According to the IEPMP 2023, from 2030, Bangladesh is planning to use co-firing ammonia with coal and blending hydrogen with natural gas in power generation to reduce emissions. Taking the experience of developed and advanced developing countries, the introduction of such technologies in power generation is assumed to cause a significant financial burden on the power and energy sector of Bangladesh. Bloomberg NEF (2023) demonstrated that using these technologies for power generation will not be cost-effective in reducing emissions. To achieve tangible emission reduction, an existing coal power plant would have to be retrofitted to be capable of co-firing ammonia with coal at energy ratios above 50 per cent. The same applies to retrofitting combined cycle gas turbine (CCGT) power plants for hydrogen. However, the environmental and social cost of these technologies, at least in the case of Bangladesh are yet to be discussed.

The CCS technology encompasses the process of absorbing carbon dioxide emissions generated by industrial operations and power plants, afterwards transferring and sequestering them underground. While it purports to reduce emissions, concerns about its efficacy, energy intensity, and leakage risk are yet to be answered. Ammonia, on the other hand, requires energy-intensive production and highly intensive infrastructure. Hydrogen is widely acknowledged as an environmentally friendly fuel option, especially when generated through the use of renewable energy resources. However, issues of energy conversion loss, storage and transportation remain as concerns.

Gaining comprehensive knowledge regarding the complete range of costs including business bodies, social and environmental costs linked to these technologies will empower policymakers, industries, and governments to make well-informed choices and decisions. The decisions made will have the potential to significantly influence energy strategy, resource allocation, and environmental policies, thereby guaranteeing that the choices made are in line with overarching sustainability objectives. Narrowing one's attention only to the technological and commercial dimensions of these technologies may result in inadvertent adverse repercussions.

Through the comprehensive assessment of financial, social and environmental costs, decision-makers can discern potential risks, vulnerabilities, and repercussions that may otherwise go unnoticed, hence mitigating the occurrence of long-term challenges. Moreover, the practice of doing a comprehensive assessment of the social and environmental costs associated with various actions or decisions promotes a sense of responsibility and transparency in the decision-making process. The aforementioned practice aids stakeholders in comprehending the inherent compromises and fosters a more inclusive and engaged methodology toward the implementation of technology.

Broadly, this paper deals with the financial, social, and environmental costs of advanced technologies in the context of Bangladesh. The specific objectives of this study are:

A. To estimate the financial cost of deploying hydrogen, and ammonia technology-based power generation as planned in the IEPMP;
B. To investigate the social implications of implementing hydrogen and ammonia solutions;
C. To estimate the environmental costs of hydrogen, and ammonia beyond carbon emissions; and
D. To put forward a set of suggestions regarding the choice of technologies concerning economic viability, social responsibility and environmental sustainability.

2. EXISTING ADVANCED TECHNOLOGIES AND THEIR FEASIBILITIES

In the quest for cleaner energy alternatives to reduce carbon emissions and combat climate change, several advanced technologies beyond the CCS, ammonia, and hydrogen are being explored and developed. Some of them are as followed:

Nuclear Fusion

Nuclear fusion, often considered the 'holy grail' of clean energy, involves merging atomic nuclei to release massive amounts of energy—similar to the process powering the sun. Unlike nuclear fission, fusion does not produce long-lived radioactive waste. The allure of fusion energy is its potential to provide an almost limitless supply of power without the carbon emissions associated with fossil fuels and with minimal radioactive waste. However, achieving controlled nuclear fusion on Earth has proven exceptionally challenging. Scientists and engineers must create and maintain extreme conditions—temperatures of millions of degrees and sufficient pressure—for fusion to occur. Projects like the International Thermonuclear Experimental Reactor (ITER) in France are making progress, aiming to demonstrate a sustained fusion reaction that produces more energy than it consumes (Brans, 2019).

Advanced Nuclear Fission

Advanced nuclear fission represents an evolution of existing nuclear technology, aiming to make it safer, more efficient, and more sustainable. This includes the development of small modular reactors (SMRs) and next-generation reactors that utilise alternative fuels, such as thorium. SMRs, in particular, offer flexibility in their deployment, being small enough to be constructed off-site and shipped to their location. This could enable nuclear energy to be utilised in areas not suitable for traditional, large nuclear power plants, as well as reduce upfront capital costs and construction times. Thorium reactors are another promising area of advancement. Thorium is more abundant than uranium, produces less waste, and the waste it does produce is less harmful and shorter-lived. Moreover, thorium reactors have inherent safety features that could mitigate the risks of meltdowns. While advanced fission technologies are still being developed and face regulatory, financial, and public acceptance challenges, they hold the potential to play a crucial role in the world's energy transition, offering a more sustainable and safer nuclear option (Plans for New Reactors Worldwide - World Nuclear Association, 2024).

Solid-state Batteries

An advancement in battery technology, solid-state batteries replace the liquid or gel electrolyte with a solid. They promise higher energy density, faster charging times, and improved safety. It is still largely in the development phase, with several companies aiming to commercialise the technology for use in electric vehicles and other applications within the next few years (Solid State Battery Design Charges in Minutes, Lasts for Thousands of Cycles, 2024).

Bioenergy with Carbon Capture and Storage (BECCS)

The BECCS involves capturing carbon dioxide produced from biomass energy production and storing it underground, effectively removing CO_2 from the atmosphere. While technically viable and in operation at a small scale, the scalability of BECCS is limited by the availability of sustainable biomass and concerns over land use and biodiversity (Gough et al., 2018).

Artificial Photosynthesis

This innovative approach aims to convert solar energy, water, and carbon dioxide (CO_2) into oxygen and energy-rich chemical fuels, such as hydrogen, methanol, or even more complex hydrocarbons, through a series of light-driven chemical reactions. Central to the concept of artificial photosynthesis are two core processes: the photoelectrochemical water splitting to produce hydrogen and oxygen, and the reduction of CO_2 using solar energy to generate hydrocarbon fuels. These processes necessitate the development of efficient and robust photocatalysts and photoelectrochemical cells that can absorb sunlight and drive the necessary redox reactions with high efficiency and under ambient conditions (Glausiusz, 2020).

Overall, the so-called new technologies are yet to be found commercially viable as an alternate option.

3. LITERATURE REVIEW

3.1 Cost Comparison of the Advanced Technologies

There is a major gap in the existing literature of the financial viability of advanced technologies. The reason is simply the fact that these advanced technologies are still very new even in the advanced first world countries. The lack of empirical evidence on whether utilising CCS, hydrogen and ammonia co-firing to generate power makes the objective of this study even more relevant in the context of Bangladesh.

Carbon Capture and Storage Unit: Hu and Zhai (2017), took a systematic approach to quantify variability and uncertainty in the cost of carbon capture and storage (CCS) for new coal-fired power plants in China under a common costing framework and examines the role of economic and policy strategies in facilitating CCS deployment. Results from the probability analysis show that the addition of amine-based CCS for 90 per cent CO_2 capture would increase the plant cost of electricity generation significantly by 58 per cent–108 per cent in comparison with the plant without CCS at 95 per cent confidence and result in a CO_2 avoidance cost within the 95 per cent confidence interval from USD 35/tonne to USD 67/tonne, which is much lower than in other countries. Prevailing literature uncovers that even in Australia one of the challenges in deploying CO_2 capture and storage is the cost of implementing capture at the large number of lignite power plants. Ho et al. (2009), investigated the cost of retrofitting CO_2 capture to a typical 500 MW lignite coal-fired power plant in Australia, and includes the costs for CO_2 separation and compression of the CO_2 in preparation for transport via pipeline to a storage site. The results show that the cost for CO_2 capture using MEA solvent is over USD 70 per tonne CO_2 avoided. Using alternative solvent technology reduces the cost to less than USD 30 (approximately AUD 35) for per tonne CO_2 reduced.

Ammonia co-firing: A techno- economic analysis on the ammonia co-firing in low-rank coal-fired power plant was done by Ahmad et al. (2022). It has been concluded that Gross revenue of an ammonia cofired power plant is decreased due to high ammonia costs. By trend of decreased ammonia cost, ammonia co-firing in coal fired power plants has a promising future to reduce CO_2 with less modification in existing coal fired power plants. Similarly, Fasihi et al. (2021) estimated the global potential of green ammonia based on hybrid PV-wind power plants. Green ammonia could be generated at the best sites in the world for a cost range of 440–630, 345–420, 300–330 and 260–290 €/tNH3 in 2020, 2030, 2040 and 2050, respectively, for a weighted average capital cost of 7 per cent. Comparing this to the decade-average fossil-based ammonia cost of 300–350 €/t, green ammonia could become cost-competitive in niche markets by 2030, and substitute fossil-based ammonia globally at current cost levels.

Hydrogen co-firing: Mneimneh et al. (2023) stated that it is difficult to ensure economic feasibility with existing technologies, considering the production, storage, and transport process of hydrogen, but it will be possible to produce grey hydrogen for USD 1.0–USD 2.1/kg, blue hydrogen for USD 1.5–USD 2.9/kg, and green hydrogen for USD 3.0–USD 7.5/kg.

3.2 Overall Environmental Effectiveness and Feasibility of Advanced Technologies

Carbon Capture and Storage (CCS): The feasibility of Carbon Capture and Storage (CCS) as a solution for achieving sustainability goals is critically challenged by several factors, which can be broadly categorised into three main areas: the utilisation of captured carbon dioxide for Enhanced Oil Recovery (EOR), the risk of stranded assets, and the lack of safe storage and monitoring mechanisms. One of the primary uses of captured carbon dioxide in the oil and gas sector is for Enhanced Oil Recovery (EOR). This process involves injecting CO_2 into oil fields to displace hard-to-reach crude oil, facilitating its extraction. Studies indicate that 80 per cent to 90 per cent of captured and stored CO_2 is repurposed for EOR (Koons, 2022).

However, this practice is criticised for not providing a permanent form of carbon storage and instead contributing to additional carbon emissions. EOR operations, as noted by investigators, do not represent a viable climate solution because they extend the lifecycle of oil extraction and perpetuate the use of fossil fuels.

The Institute for Energy Economics and Financial Analysis highlights the significant risk of stranded assets associated with CCS. By extending the operational life of fossil fuel power plants, CCS necessitates the development of new support infrastructure, which could become obsolete with the increasing availability and viability of renewable energy technologies (Koons, 2021). This risk of stranded assets is economically significant, as it involves potentially billions of dollars in investments that may not yield returns if fossil fuel infrastructure becomes redundant in a low-carbon future.

Effective monitoring of underground carbon storage, a crucial component of CCS, is currently inadequate. Ensuring that sequestered carbon remains underground requires continuous monitoring over centuries, a challenge that is not yet met by existing technologies. The absence of reliable monitoring systems raises concerns about the long-term efficacy and safety of carbon storage. Moreover, the high costs and low profitability of CCS further hinder its adoption. As per (Symons, 2023), the economic burden of CCS projects, which can range from €14 to €110 per tonne of CO_2, makes them less attractive to stakeholders.

Additional challenges complicate the feasibility of CCS, including limited viable storage sites and the need for extensive transportation infrastructure. A pertinent example is the cancellation of a USD 3 billion CCS pipeline project in the US Midwest due to concerns over leaks and construction damage, highlighting the practical difficulties of implementing large-scale CCS projects. Furthermore, stored CO_2 poses risks of leakage, which can negate the benefits of sequestration. Natural seismic activity or improper management can compromise the integrity of storage sites, as evidenced by the In Salah gas project in Algeria, where CO_2 leakage was observed along fissures in the cap rock.

The process of injecting CO_2 into geological formations has also been linked to induced seismicity. For instance, the Weyburn oil field in Canada experienced increased seismic events attributed to significant CO_2 injections. These risks and the associated uncertainties underscore the complexities and limitations of CCS as a sustainable solution to climate change.

Hydrogen: The environmental viability of hydrogen co-firing is significantly influenced by the methods used to produce hydrogen. Currently, the predominant method for hydrogen production is steam methane reforming (SMR) from natural gas, which generates substantial CO_2 emissions. Without transitioning to green hydrogen production methods, such as electrolysis powered by renewable energy sources, the potential for substantial reductions in carbon emissions remains limited. Even blue hydrogen, which is produced from natural gas with carbon capture and storage, has been found to have a larger greenhouse gas footprint than traditional fossil fuels like gas, coal, or diesel oil used for heating (Lakhani, 2023).

Adapting existing power generation infrastructure to accommodate hydrogen safely is both costly and complex due to hydrogen's unique combustion characteristics. Hydrogen burns with a higher flame speed and a broader flammability range compared to natural gas, necessitating significant modifications to existing combustion systems, particularly at higher blending ratios. This adaptation is not only a technical challenge but also an economic one, as it requires substantial investment.

The energy density of hydrogen by volume is much lower than that of natural gas, leading to reduced efficiency in energy production when hydrogen is substituted directly. More energy may be required to achieve the same output, which could negate the benefits of lower carbon emissions. This reduced efficiency highlights the need for careful consideration of the energy production process and potential adjustments to infrastructure to optimise performance.

Furthermore, hydrogen's small molecular size makes it prone to leakage through small openings, posing significant safety risks due to its high flammability. These leaks can also have environmental impacts, as escaping hydrogen can influence atmospheric chemistry and potentially affect the ozone layer. The propensity for hydrogen to leak adds another layer of complexity to its adoption as a co-firing fuel, emphasising the need for robust safety measures and monitoring systems.

Ammonia: The environmental viability of ammonia combustion as a carbon-free fuel is mitigated by the emission of other greenhouse gases, such as nitrous oxide (N2O). The production of N2O during ammonia combustion poses significant environmental risks due to its high global warming potential, which is substantially greater than that of CO_2 over a 100-year timescale (Bloomberg NEF, 2022).

Adapting existing power plants to safely handle and burn ammonia alongside conventional fuels requires extensive modifications. Ammonia's corrosive and toxic nature poses serious risks to human health, necessitating stringent safety protocols. Additionally, ammonia has unique combustion properties, such as a higher ignition temperature and a narrower flammability range compared to traditional fuels, which can impact combustion efficiency and operational stability. These differences require significant adjustments to combustion systems to ensure safe and efficient operation (Giseburt, 2024).

The energy density of ammonia is lower than that of fossil fuels like coal and natural gas. Consequently, more ammonia must be burned to produce the same amount of energy, potentially decreasing the overall efficiency of power generation systems. This reduced energy density necessitates careful consideration of fuel logistics and energy production strategies to mitigate efficiency losses.

Ammonia co-firing also poses health risks due to air pollution. Even if pollution levels from ammonia co-firing are comparable to those from coal-fired power plants, the impact on air quality and human health remains a concern. For example, in regions like Japan, where coal plants contribute significantly to PM2.5 concentrations and premature deaths, the environmental and health implications of ammonia co-firing warrant careful scrutiny. Ensuring that ammonia combustion does not exacerbate air quality issues is essential for its acceptance as a cleaner energy alternative.

4. ADVANCED TECHNOLOGIES IN THE CONTEXT OF IEPMP 2023

The IEPMP 2023 underlines the power development plan for the next five years under three different scenarios: Reference Scenario (REF), Advanced Technology Scenario (ATS), and Net Zero Scenario (NZS). In the ATS and NZS, the usage of advanced technologies to achieve the decarbonisation goals has been mentioned. However, in the final IEPMP, it was assumed that NZS is not feasible for Bangladesh and only ATS has been considered for the decarbonising power and energy sector in Bangladesh. The key characteristic of ATS is the implication of energy and environmental policies to ensure a stable energy supply and strengthen climate action will be successful to a certain extent. The main assumption is introduction of advanced technologies will progress under the ATS, which will accelerate cost reduction. As a result, under this scenario, carbon capture and storage units, ammonia, and hydrogen are said to be introduced for power generation. IEPMP sets the goal to have up to 40 per cent of electricity generated from clean energy sources such as CCS, nuclear, hydrogen,

Table Technology Setting: Power Generation Sector

Sector	Net Zero Scenario (NZS)	Advanced Technology Scenario
Gas-fired	100% hydrogen single-firing will start around 2035 and replace 70% of gas-fired power through 2050. Gas-fired with CCS will start around 2036 and achieve 30% of the gas-fired power in 2050	20% hydrogen co-firing will start around 2035 (2037), 50% hydrogen co-firing will start around 2040 (2045). Gas-fired with CCS will start around 2036 (2040) and achieve 77 TWh (38 TWh) in 2050
Coal-fired	50% ammonia co-firing around 2030 and 100% ammonia single-firing around 2042	20% ammonia co-firing around 2030 (2035) and 50% ammonia co-firing around 2035 (2040)

Source: IEPMP, 2023.

and ammonia co-firing. To achieve this goal, the master plan introduces hydrogen (H2) and ammonia (NH3) in 2030.

4.1 Carbon Capture and Storage in the IEPMP 2023

The IEPMP 2023 mentions the introduction of the carbon capture and storage unit (CCS) to reduce carbon emissions from CCGT or gas-based power plants. On introduction of CCS in gas-fired power plants from 2040 and onwards has been considered in IEPMP. In the IEPMP, CCS for gas-fired thermal power plants is scheduled to start in 2040. Nevertheless, it is desirable to start preliminary studies on suitable sites and technologies for CCS. It is important to monitor the progress of these projects to accumulate information as the basis for the study to establish an efficient plan.

Towards 2050, the composition of coal-fired power with lower fuel costs will decrease, while that of hydrogen-fired power and gas-fired power with CCS, with high generation costs, will increase. However, most of the gas-fired power plants that will be newly developed after 2030 will be the latest combined-cycle models with significantly higher thermal efficiency than the power plants currently in operation.

Table 1: Year-wise plan for the introduction of new technologies 'CCS'

Year	Total Primary Energy Supply (Million TOE)	Composition (%)	Average Growth Rate (%)
2019	0.0	0.0	-
2030	0.0	0.0	-
2041	3.7	3.2	-
2050	10.1	6.0	9.5

Source: IEPMP, 2023.

4.2 'Hydrogen' in the IEPMP 2023

The IEPMP 2023 shows the timing of the introduction of hydrogen (H2) and ammonia (NH3) in gas- and coal-fired thermal power systems. According to the final IEPMP 2023, it will be necessary to consider specific plants for application in the future.

The plan further indicates that it will probably be necessary to apply gas-fired power plants with 20 per cent hydrogen co-firing starting in 2037 and upgraded to 50 per cent in 2045. Gas-fired with

Table 2: Introduction of new technologies-'Hydrogen' in IEPMP

Hydrogen cofiring with gas	
Year	Incorporation of hydrogen to promote clean energy
2036	Gas-fired with CCS will start
2037	Gas-fired power plants with 20 per cent hydrogen co-firing
2045	Apply gas-fired power plants with 50 per cent hydrogen co-firing
2050	Gas-fired with CCS will achieve 30 per cent
Hydrogen single-firing	
2035	100 per cent hydrogen single-firing
2050	Replace 70 per cent of gas-fired power through 2050

Source: IEPMP, 2023.

CCS will start around 2036 and achieve 30 per cent of the gas-fired power in 2050. The planned hydrogen deployment indicates the adaptation of blue and grey hydrogen for power generation. The deployment of green hydrogen is not clear in the IEPMP final report.

In the case of hydrogen single-firing, IEPMP states that 100 per cent hydrogen single-firing will start around 2035 and replace 70 per cent of gas-fired power through 2050. The hydrogen roadmap for Bangladesh is currently being drafted by the MoPEMR.

Along with the power sector, under the net zero scenario (NZS), hydrogen will be used in the road sector as 10 per cent of trucks and buses (TRBSs) will become fuel-cell vehicles (FCVs) in 2050. Similarly, in the industrial sector, non-electricity energy will shift to hydrogen through 2050.

Table 3: Year-wise plan for the introduction of new technologies- 'Hydrogen'

Year	Total Primary Energy Supply (Million TOE)	Composition (%)	Average Growth Rate (%)
2019	0.0	0.0	-
2030	0.0	0.0	-
2041	4.9	4.2	-
2050	14.3	8.5	10.2

Source: IEPMP, 2023.

4.3 'Ammonia' in the IEPMP 2023

The new IEPMP has laid out the plan to introduce ammonia co-fired as soon as 2030 stating it to be inevitable for clean energy deployment in Bangladesh under the advanced technology scenario. IEPMP plans to co-fire the coal power plants with 20 per cent NH3 starting in 2035 and upgrading to 50 per cent in 2040. After 2037, the introduction of CCS should also be considered to further reduce CO_2 emissions in the power plants with ammonia cofired. Hundred (100) per cent ammonia single-firing around 2042 for power generation in Bangladesh. Unlike hydrogen co-firing, there is no mention of ammonia to be used in any other sector.

Table 4: Year-wise plan for the introduction of new technologies 'Ammonia'

Year	Total Primary Energy Supply (Million TOE)	Composition (%)	Average Growth Rate (%)
2019	0.0	0.0	-
2030	0.2	0.3	-
2041	1.2	1.0	15.5
2050	0.6	0.3	-6.4

Source: IEPMP, 2023.

5. SUPPLY CHAIN OF FUELS

To understand the potential implications of using CCS, ammonia, and hydrogen in power generation, it is crucial to depict the supply chain of these technologies in a power plant.

5.1 Detailed supply chain of CCS

The supply chain for Carbon Capture and Storage (CCS) in the context of a power plant involves several key stages, each with its complexities and challenges. The stages are as follows as per Office of Fossil Energy and Carbon Management, Department of Energy of USA:

Stage 1- Capture: This is the first stage in the CCS process, where CO_2 is captured from power plant emissions. There are three primary methods for capturing CO_2:

- **Pre-combustion Capture:** Involves converting fossil fuels into a gas mixture containing hydrogen and carbon dioxide before combustion. The CO_2 is then separated from the gas mixture.
- **Post-combustion Capture:** This involves capturing CO_2 from the flue gases after fossil fuels have been burned. This is the most common method for retrofitting existing power plants due to their applicability and compatibility with existing infrastructure. Unlike pre-combustion capture or oxy-fuel combustion, post-combustion capture can be added to power plants without significantly altering the existing combustion process.
- **Oxy-fuel Combustion:** This method involves burning fossil fuels in an environment of pure oxygen, rather than in air, which is a mixture of nitrogen, oxygen, and small amounts of other gases. Since air is approximately 78 per cent nitrogen and 21 per cent oxygen, burning fuels in the air results in flue gases that contain a large volume of nitrogen, along with CO_2 and water vapor.

Stage 2- Compression and Purification: Once captured, the CO_2 needs to be compressed to a liquid state and purified. Compression is necessary for transportation, and purification ensures that impurities, that could cause issues in transport or storage, are removed.

Stage 3- Transportation: The compressed and purified CO_2 is then transported to a storage site. Transportation can be done in several ways:

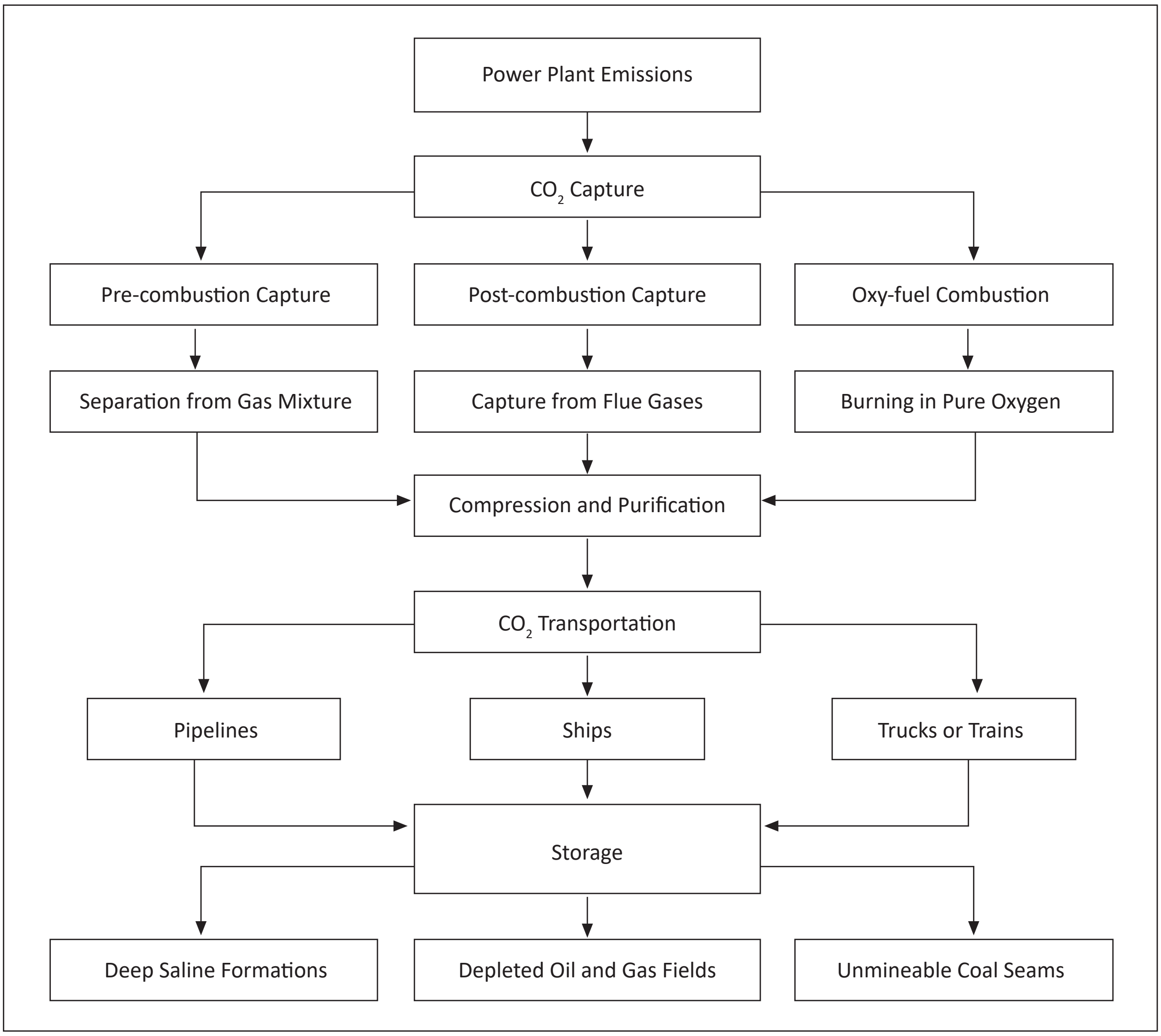
- **Pipelines:** This is the most common method for transporting large quantities of CO_2, especially over land.
- **Ships:** For locations inaccessible by pipelines, specially designed ships can be used.
- **Trucks or Trains:** These are less common and typically used for smaller quantities or shorter distances.

Stage 4- Storage: The final stage of the CCS process is storing the CO_2 in geological formations. There are several types of storage sites:

- **Deep Saline Formations:** These are porous rock formations filled with brine, located several kilometers underground.
- **Depleted Oil and Gas Fields:** These are existing fields that have been depleted of their natural resources and can be repurposed for CO_2 storage.
- **Unmineable Coal Seams:** CO_2 can be stored in coal seams that cannot be economically mined, where it absorbs the surface of the coal.

Each stage of the CCS supply chain presents unique challenges and requires specialised technology and expertise. The capture stage is energy-intensive and expensive, transportation needs a robust infrastructure, and storage demands thorough geological understanding and long-term monitoring to ensure safety and effectiveness (figure 1).

Figure 1: Supply chain of CCS in Power Generation



Source: Authors' illustration.

5.2 Detailed supply chain of Hydrogen

The supply chain for hydrogen, particularly when it's imported for co-firing in power plants, involves several key stages. Here's a breakdown of the process from the point of import to its utilisation in power plants as per Hydrogen and Fuel Technologies Office, Department of Energy of USA:

Stage 1- Import: Hydrogen can be imported in various forms depending on the technology and infrastructure available. The common forms include:

- **Compressed or Liquefied Hydrogen:** Hydrogen can be transported in high-pressure tanks (compressed) or as a cryogenic liquid (liquefied).
- **Chemical Carriers:** Hydrogen can be bound to other chemicals like ammonia or liquid organic hydrogen carriers (LOHCs), which are easier to transport and can be converted back to hydrogen at the destination.

Stage 2- Offloading and Storage at Port: Upon arrival at the importing country, hydrogen is offloaded from ships, trucks, or trains. It may be stored temporarily at the port in appropriate facilities depending on its form (e.g., cryogenic tanks for liquefied hydrogen).

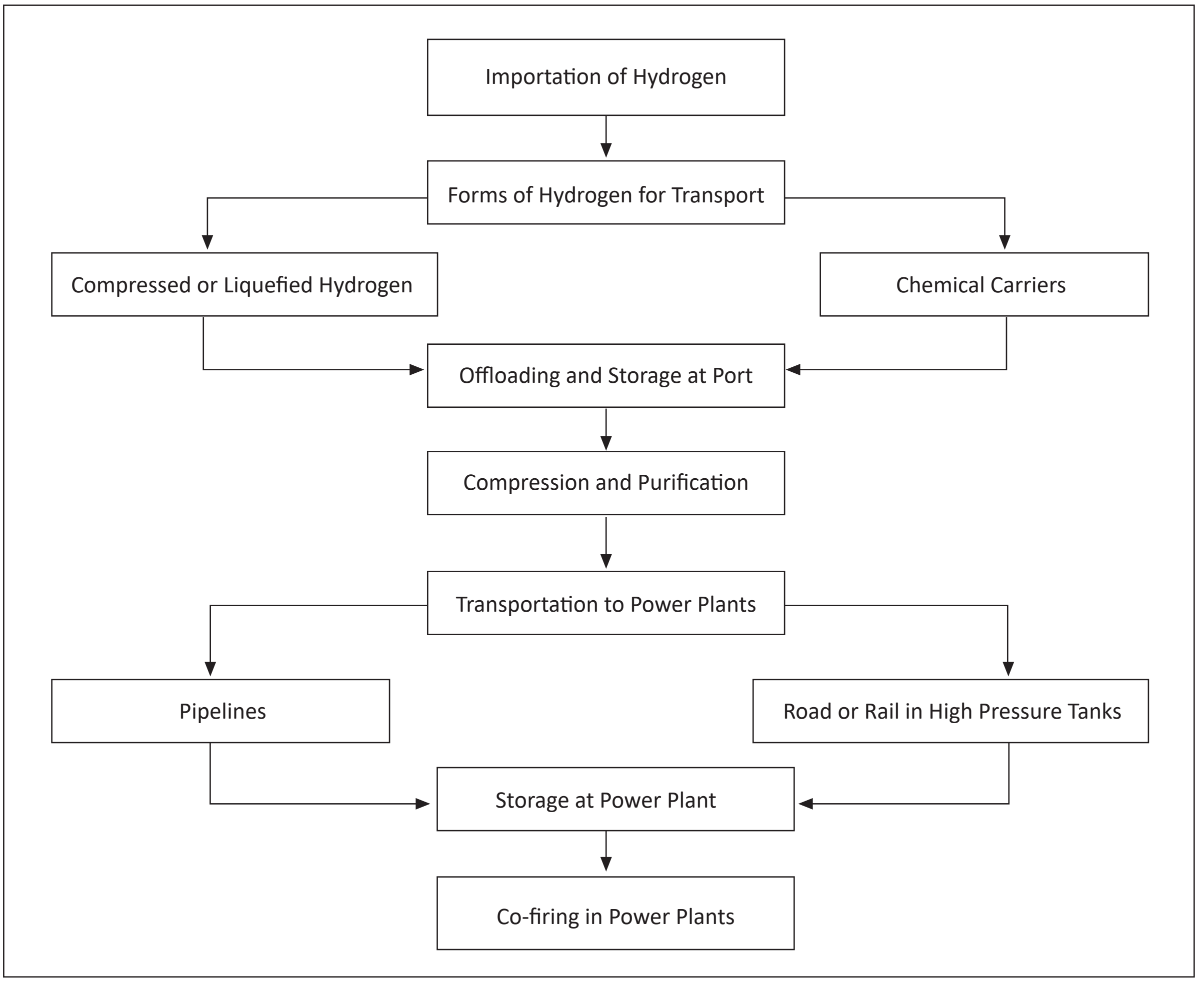
Stage 3- Conversion and Purification: If hydrogen is imported in a bound form (like ammonia or LOHCs), it needs to be converted back into hydrogen gas. This step might also include purification processes to ensure the hydrogen meets the required quality standards for co-firing in power plants.

Stage 4- Transportation to Power Plants: After conversion and purification, hydrogen is transported to power plants. This can be done through pipelines, which are the most efficient for large quantities, or via road or rail in high-pressure tanks, especially for plants not connected to a hydrogen pipeline network.

Stage 5- Storage at Power Plant: Upon arrival at the power plant, hydrogen is stored in on-site tanks. These tanks must be capable of handling hydrogen's unique properties, like its low density and high flammability.

Stage 6- Co-firing in Power Plants: Hydrogen is then used for co-firing in the power plant, which involves blending it with the primary fuel (usually coal or natural gas) for combustion. This requires

Figure 2: Supply chain of Hydrogen in Power Generation



Source: Authors' illustration.

modifications to the power plant's combustion system to handle hydrogen's characteristics, such as its higher flame speed and lower ignition energy compared to conventional fuels.

This supply chain (figure 2) underscores the complexities involved in incorporating hydrogen into existing energy systems, particularly for countries relying on imported hydrogen. It involves a series of specialised processes and infrastructure, from the importation stage to the actual co-firing in power plants, each with its own technical, economic, and safety considerations.

5.3 Detailed supply chain of Ammonia

The ammonia supply chain, especially for its importation for co-firing in power plants, encompasses multiple discrete stages. This process includes the transportation, storage, conversion, and ultimate application of the resource in power generation. Below is a concise summary of each step as per Ammonia Storage and Transportation, Department of Energy of USA:

Stage 1- Import: Ammonia is imported, typically in its liquefied form due to its higher density in this state, which makes transportation more efficient. It is transported using specialised ammonia carriers (ships) equipped with refrigerated or pressurised tanks.

Stage 2- Offloading and Storage at Port: Upon arrival at the port, the liquefied ammonia is offloaded from the ships. This is done using pipelines that connect the ship to large refrigerated or pressurised storage tanks onshore. These storage facilities are designed to handle the corrosive and hazardous nature of ammonia.

Stage 3- Transportation to Power Plants: From the port, the ammonia is transported to power plants. This can be achieved through pipelines, which are ideal for large quantities over long distances, or by road or rail using tankers specifically designed for ammonia.

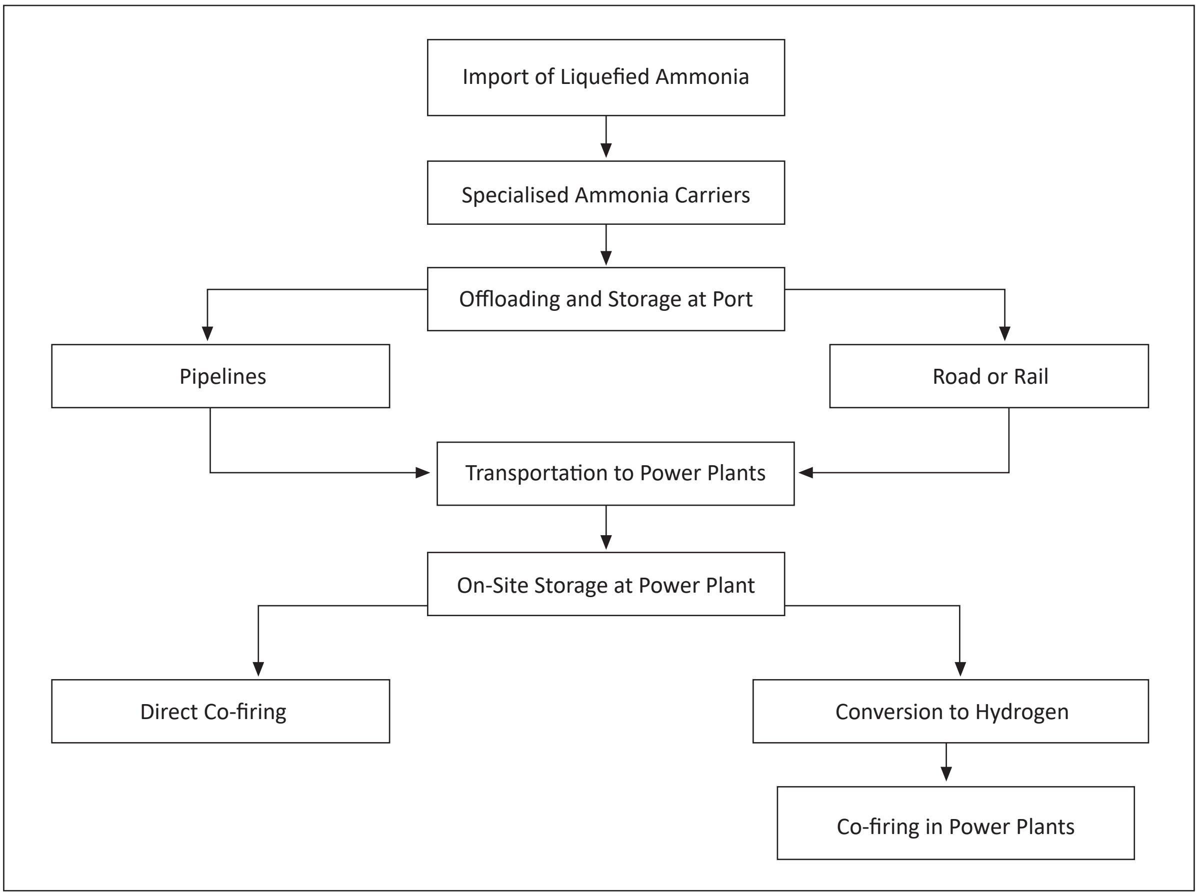
Stage 4- On-Site Storage at Power Plant: At the power plant, ammonia is stored in large tanks similar to those at the port. These tanks are also designed to contain ammonia safely, considering its corrosive properties and the risks associated with its toxicity and flammability.

Stage 5- Conversion to Hydrogen: If the power plant co-fires ammonia directly, this step is not necessary. However, in some setups, ammonia may be cracked back into hydrogen and nitrogen before combustion. This requires a reforming process, which is energy-intensive and needs to be carefully managed to avoid releasing nitrogen oxides (NOx), a harmful pollutant.

Stage 6- Co-firing in Power Plants: Ammonia, either directly or after conversion to hydrogen, is then used for co-firing in the power plant. Co-firing with ammonia requires modifications to the combustion system to handle its unique combustion characteristics. Ammonia burns with a lower flame temperature than conventional fuels, and controlling NOx emissions is a significant concern.

This supply chain (figure 3) illustrates the complexities involved in handling and utilising ammonia, especially when imported for use in power generation. Each stage of the process requires specialised equipment and safety measures, reflecting the hazardous nature of ammonia and the technical challenges associated with its use as a fuel for co-firing in power plants.

Figure 3: Supply chain of Ammonia in Power Generation



Source: Authors' illustration.

6. ESTIMATING FINANCIAL, SOCIAL AND ENVIRONMENTAL COSTS OF ADVANCED TECHNOLOGIES

6.1 Financial Cost of Hydrogen and Ammonia Co-firing in a Power Plant

The paper estimates the cost of deploying power generation from ammonia co-firing and hydrogen co-firing in 2030, 2041, and 2050 according to the power generation plan of the IEPMP. The financial cost calculation of the technologies is based on the Bloomberg New Energy Finance Levelised Cost of Electricity (LCOE) model.

Case 1: Gas retrofits with hydrogen (blue hydrogen): Calculating the total life cycle financial cost of the power plant.

- Total life cycle cost of the power plant= CAPEX of blending hydrogen with gas in an existing gas-based power plant+ OPEX (fixed+ variable)

Case 2: Coal retrofits with ammonia: Calculating the total life cycle economic cost of the powerplant.

- Total life cycle cost of the power plant= CAPEX of blending ammonia with coal in an existing coal-based power plant + OPEX (fixed+ variable)

Where,

CAPEX: Include equipment costs (e.g., turbines, towers, modules), non-equipment construction costs (e.g., foundations, facilities, security, on-site electrical), and pre-constructions costs (e.g., permitting, application, siting, and land). It excludes the cost of grid connection and transmission.

OPEX (Fixed): Annual operating costs that will remain fixed regardless of total generation levels, e.g., administrative, rent/lease contract costs, insurance, fees.

OPEX (Variable): Cost that are dependent on generation, e.g., fuel, carbon, and maintenance (if there is no fixed contract).

Total lifetime of the powerplant: 20 years

6.2 Social Cost of Hydrogen and Ammonia Co-firing

This study intends to assess the social cost of technologies in the IEPMP by analysing their opportunity cost using available cost-related data. Social cost, defined as opportunity cost, is the total value of resources and benefits that society foregoes by choosing to adopt and utilise a certain technology. This evaluation extends beyond the direct financial costs associated with the technology. It considers the possible other uses of resources that were not investigated since they were allocated to the chosen technology. This involves considering alternative projects or opportunities that could have been undertaken with the same investment, offering a more comprehensive view of the actual cost of technological decisions in terms of financial expenses and potential opportunities in various areas like environmental, social, and economic progress.

The social cost will be determined by evaluating the potential renewable energy output achievable with the current investment level and the employment opportunities that may be generated with a similar capacity expansion.

6.3 Estimating the Environmental Cost of Hydrogen Co-firing

The environmental cost of the technologies is being calculated based on their potential carbon emissions. The environmental cost of a technology based on its carbon emissions refers to the negative impact on the environment resulting from the release of greenhouse gases, particularly carbon dioxide (CO_2), into the atmosphere during the production, use, and disposal of that technology.

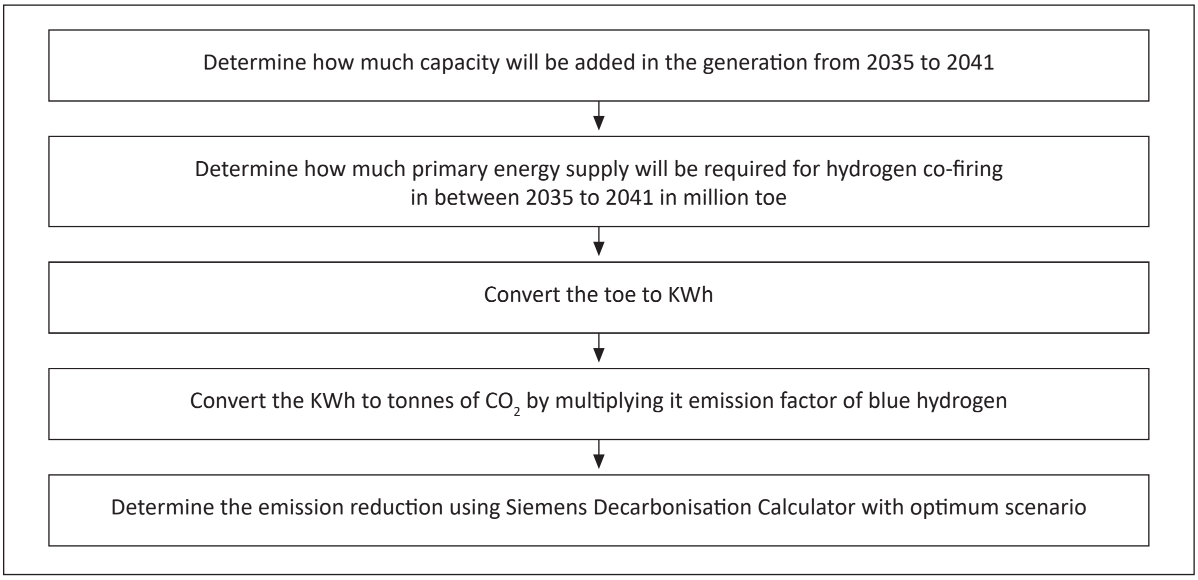
To determine the environmental cost of these three technologies, the observations and hypotheses were extracted concerning these technologies from the IEPMP 2023. They are:

a) CCS will be available in the co-fired power plants while focusing on the greenfield CCS rather than building a new one from scratch
b) 20 per cent hydrogen co-firing will start from 2035
c) 20 per cent ammonia co-firing will start from 2030

All the data concerning capacity generation to be added has been extracted from the IEPMP 2023.

To determine the CO_2 emissions from hydrogen co-firing and how much CO_2 emissions will be reduced, the following procedures will be followed:

Figure 4: Analytical Framework for calculating carbon emission in hydrogen co-firing

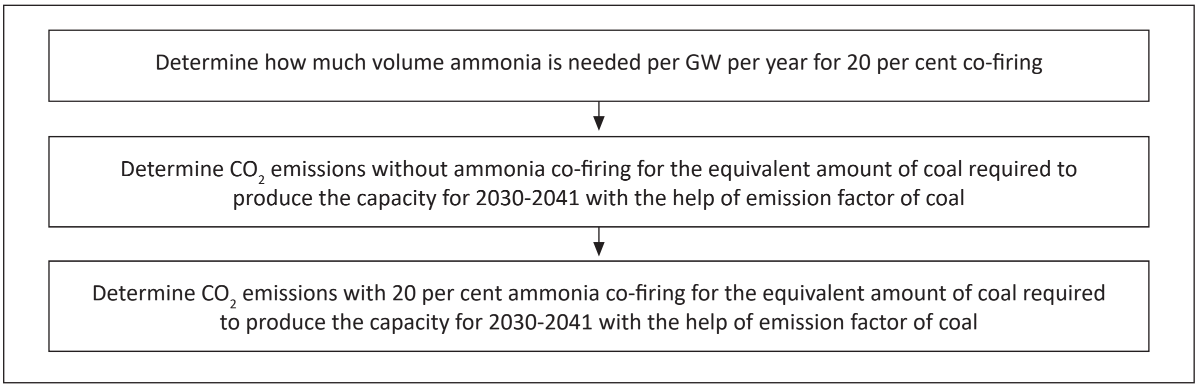


Source: Authors' illustration.

6.4 Environmental Cost of Ammonia Co-firing

To determine the CO_2 emissions from ammonia co-firing and how much CO_2 emissions will be reduced, the following procedures will be followed:

Figure 5: Analytical Framework of calculating carbon emission in ammonia co-firing



Source: Authors' illustration.

6.5 Data used for Estimating Costs

The data for the estimation of this study is collected from different secondary sources, mainly from IEPMP, MoPEMR, Bloomberg, and the Ministry of Finance.

6.5.1 Data for Environmental Cost Estimation

To determine the environmental cost of hydrogen and ammonia co-firing, the study collected the requirements of these two components in terms of toe (total oil equivalent) from IEPMP. To calculate the CO_2 cost saving, the optimum setting of the factories has been used in the Siemens Decarbonisation Calculator; the data of which was gathered from KIIs.

6.5.2 Data for Financial Cost Estimation

The numbers and values of the CAPEX and OPEX for these technologies are derived from the estimations provided in Bloomberg's report on Bangladesh titled Bangladesh Power Sector at the Crossroads.

The targeted power generation capacity from hydrogen and ammonia is retrieved from the IEPMP 2023 for the calculation of total financial cost.

6.5.3 Data for Social Cost Estimation

To estimate the social cost, the data were collected from the Bloomberg Report titled Bangladesh Power Sector at the Crossroads, and the required investment was calculated by the authors from the IEPMP data.

7. RESULTS OF ESTIMATION OF FINANCIAL, SOCIAL, AND ENVIRONMENTAL COSTS AND RESULTS

The following section represents the calculation or estimation of the environmental cost, financial cost, and social cost of deploying hydrogen cofiring and ammonia cofiring for power generation in Bangladesh according to IEPMP.

7.1 Results of Estimation of Financial Cost

7.1.1 Cost of power generation using Coal retrofitted with ammonia

By using the data and methodology it has been estimated that the investment required per MW of ammonia retrofitted with the existing coal powerplant in 2030 will be BDT 2.83 crore. In 2050 the investment per MW electricity produced from ammonia cofired power plants will be double compared to that of 2030 and reach BDT 4.23 crore (Annex 1). Very high Capital cost if the main reason of such high investment cost. During 2023-2030, 1300 MW of electricity from ammonia co-fired with coal will be deployed. The total investment to deploy to generate 1300 MW from the ammonia according to IEPMP will be BDT 3685.37 crore. The rest 1300 MW will be deployed during 2031-2041, which will require a total investment of BDT 5502.34 crore in 2041 for another 1300 MW of electricity (table 5)

Annex 1 Coal retrofitted with Ammonia

Variable	Unit	2023	2030	2050
Capex	USD/MW	187,000.00	215,721.33	322,692.70
Fixed opex	USD /MW/Year	37,400.00	41,996.90	62,086.20
Fixed opex lifetime	USD/MW	748,000.00	83,9938.00	1,241,724.00
Variable opex	USD/MW	0.00	0.00	0.00
Lifetime	Years	20.00	20.00	20.00
Per MW total cost	USD/MW	224400.00	257,718.23	384,778.90
Per MW total cost	BDT/MW	24,684,000.00	28,349,005.30	42,325,679.00

Source: Authors' calculation.

Table 5: Cost of Ammonia deployment in Bangladesh according to IEPMP

	2023-30	2031-41	2042-50
Coal retrofitted with ammonia Generation Capacity According to IEPMP (MW)	1300.00	1300.00	0.00
Per MW Investment Required (Crore BDT)	2.47	2.83	4.23
Investment Required to add generation capacity according to IEPMP (Crore BDT)	3685.00	5502.00	0.00

Source: Authors' estimation, 2024.

7.1.2 Cost of power generation using CCGT retrofitted with hydrogen

The investment estimations of cofiring hydrogen with natural gas are similar to that of ammonia co-fired with coal, in fact, the numbers are even higher for the hydrogen co-fired with gas power plants. The cost to deploy per MW of CCGT with hydrogen cofired power plants will be BDT 3.55 crore in 2030, which will reach Tk 5.30 crore per MW (Annex 2) in 2050. However, hydrogen co-fired with gas will be introduced in 2035 hence the cost will be incurred at that time. The cost of 1600 MW hydrogen co-fired power generation will be BDT 5673.22 crore in 2041. For the next generation capacity of 1600 MW, the cost incurred will be BDT 8472.41 crore in 2050. As it is assumed that the hydrogen will be co-fired with expensive imported LNG the required investment is much higher even can spike more in future given the volatile LNG global spot market.

Annex 2 CCGT retrofitted with Hydrogen

Variable	Unit	2023	2030	2050
Capex	USD/MW	240,000.00	276,861.60	414,151.00
Fixed opex	USD/MW/Year	40,500.00	45,478.13	67,232.25
Fixed opex lifetime	USD/MW	810,000.00	909,562.50	1,344,645.00
Variable opex	USD/MW	2.05	2.28	3.41
Lifetime	Years	20.00	20.00	20.00
Per MW total cost	USD/MW	280502.05	322,342.00	481,386.66
Per MW total cost	BDT/MW	30855225.70	35,457,620.60	52,952,532.00

Source: Authors' calculation.

Table 6: Cost of hydrogen deployment in Bangladesh according to IEPMP

	2023-30	2031-41	2042-50
CCGT retrofitted with hydrogen Generation Capacity According to IEPMP (MW)	0.00	1600.00	1600.00
Per MW Investment Required (Crore BDT)	-	3.55	5.30
Investment Required to add generation capacity according to IEPMP (Crore BDT)	0.00	5673.00	8472.00

Source: Authors' estimation, 2024.

7.2 Results of Estimation of Environmental Costs

7.2.1 Environmental Cost of Hydrogen Co-firing

Between the years 2035 and 2041, a total of 1.6 gigawatts (GW) of power will be generated using a method called hydrogen co-firing. This method requires a total of 4.9 million tonnes of oil equivalent (toe) of hydrogen to be used across these seven years. The plan details how much power capacity will be added each year, as well as the amount of hydrogen required for that year, as shown in Table 7.

Table 7: Addition of Power Generation Capacity and Requirement of Hydrogen in Power Generation

Year	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**Total**
Capacity Addition (GW)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	1.60
Primary Energy Supply (million toe)	4.90	4.90	4.90	4.90	4.90	4.90	4.90	34.30

Source: Authors' calculations based on IEPMP.

Table 7 breaks down the annual addition of power generation capacity and the hydrogen needed for power generation from 2035 to 2041. Each year, the capacity will increase by 0.22 GW, totaling 1.6 GW over seven years. The amount of hydrogen needed annually for this process is 4.9 million toe, adding up to 34.3 million toe over the seven years.

Now, 34.3 million toe is converted to kilowatt-hours (kWh). Given that 1 toe is approximately equal to 11,628 kWh,

34.3 million toe = (34.3x106) x 11,628 KWh = 3.99x1011 KWh

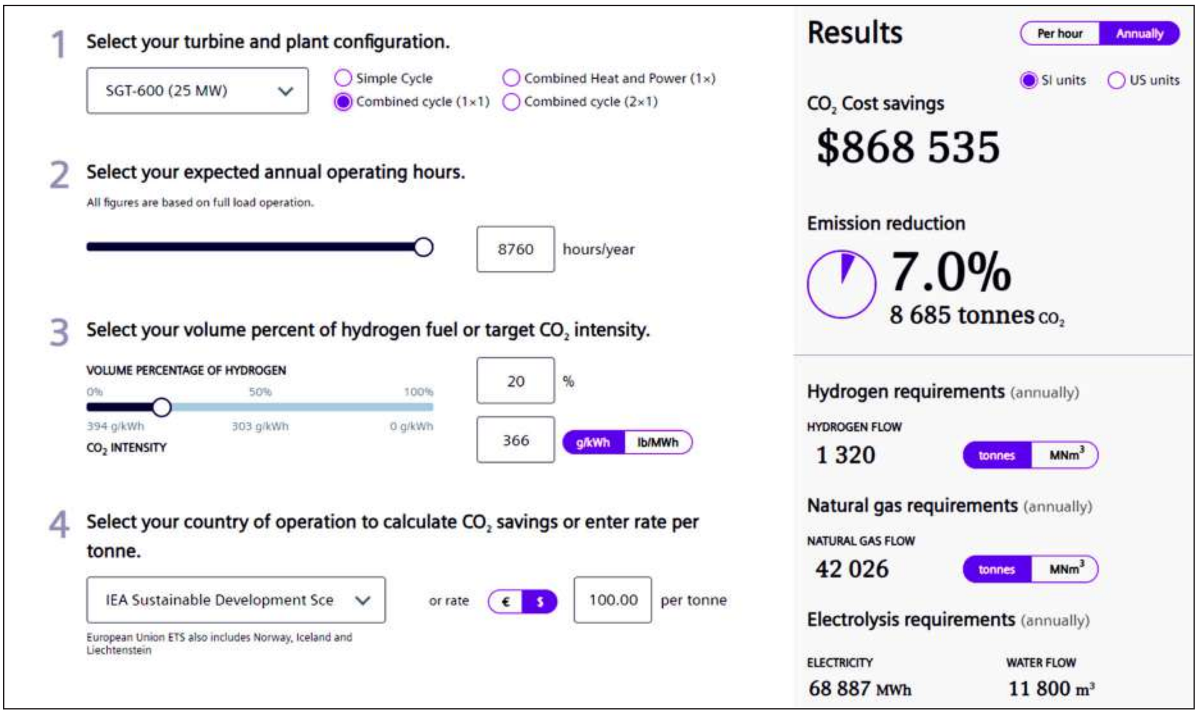
Now, to convert this into tonnes of CO_2, we need the emission factor of Hydrogen.

Average emission factor of Blue Hydrogen is 0.015 kg CO_2 per KWh.

So, total emission of CO_2 will be = (3.99x1011) x (0.015) = 5985000 tonnes

Using a decarbonisation calculator from Siemens, assuming a scenario where 20 per cent of the power is generated by hydrogen co-firing and aligning with the International Energy Agency's Sustainable Development Scenario, it is estimated that CO_2 emissions will be reduced by 8,685 tonnes per year. Over the seven-year period (2035-2041), this amounts to a total CO_2 reduction of 8,685 x 7 =60,795 tonnes. Despite this reduction, the total amount of CO_2 emissions produced by co-firing hydrogen in the same timeframe is still significant.

Figure 6: Calculation of CO_2 reduction using Siemens Decarbonisation Calculator



Source: Authors' illustration.

7.2.2 Environmental Cost of Ammonia Co-firing

In this span of years, table 8 represents the power generation capacity addition.

Table 8 Power generation capacity addition according to IEPMP

Capacity Addition (GW)			
2023-30	**2031-41**	**2042-50**	**Total**
1.3	1.3	0	2.6

Source: IEPMP, 2023.

The volume of ammonia needed per GW per year is assumed to be 500000 tonnes for 20 per cent co-firing.

So, in the span of 2030-2041, for 2.6 GW capacity addition, (500000 x 2.6 x 12) = 15600000 tonness of ammonia will be required.

Now, 2.6 GW = 2600000 KWh.

CO_2 Emissions from Coal without Ammonia Co-firing:

- The emission factor for coal is approximately 2.2 lbs of CO_2 per kWh.
- Total CO_2 emissions without ammonia co-firing = 2.2 lbs/kWh × 2600000 kWh. = 5720000 lbs of CO_2

Reduction in CO_2 Emissions Due to Ammonia Co-firing:

Assuming a 20 per cent reduction in CO_2 emissions due to 20 per cent ammonia co-firing, the reduction is 20 per cent of 5720000 lbs = 1144000 lbs of CO_2.

Total CO_2 Emissions with Ammonia Co-firing:

- Total emissions with ammonia co-firing = Total emissions without ammonia co-firing - Reduction due to ammonia.
- Total CO_2 emissions with ammonia = 5720000 lbs – 1144000 lbs = 4576000 lbs of CO_2.

Since 1144000 lbs CO_2 is reduced in one hour, the annual CO_2 reduction is = 1144000 × 24 × 365 = 10,021,440,000 lbs = (10,021,440,000/2000) tonne = 5010720 ton.

So, in 12 years (2030-2041), CO_2 reduction will be 5010720 tonnes × 12 = 60128640 tonnes

7.2.3 Environmental Costs of CCS based Power Generation

According to multiple plants observed in European Union as per Cebrucean et al, CCS with the lowest capacity can capture 7 tonnes CO_2/day and the highest capturing capacity is 60 tonnes CO_2/day.

From the above observations,

The minimum amount of CO_2 capture will be = 365 × 7 × 7 = 17885 tonnes and,

The maximum amount of CO_2 capture will be = 365 × 7 × 60 = 153300 tonnes

The same study has also found that the application of CCS technologies can reduce the net efficiency of a plant by up to 14 per cent. Based on the technology used, the cost of electricity may increase by 30-70 per cent.

Another study found that a 1 per cent increase in efficiency of the power plants can reduce CO_2 by 2-3 per cent. So, if the efficiency of the power plants is decreasing and the amount of captured CO_2 is only between 17885 tonnes to 153300 tonnes, the environmental cost of CCS becomes too expensive compared to the opportunity costs.

7.3 Results of Estimation of Social Costs

7.3.1 Opportunity cost in terms of traditional renewable energy sources

As per IEPMP, by 2041, a generation capacity of 4,200 MW will be achieved through the addition of 2,600 MW from ammonia and 1,600 MW from hydrogen, requiring a total investment of 14,861 crore BDT. Given the investment requirements for renewable energy, each megawatt (MW) of solar power will require 5.5 crore BDT, and wind power will require 20.1 crore BDT. This translates to an opportunity cost where the same investment could alternatively generate 2,654 MW of solar power or 739 MW of wind power, as detailed in Table 9. This illustrates the potential benefits of directing investments towards renewable energy sources, highlighting significant increases in generation capacity for solar and wind power compared to the planned investments in ammonia and hydrogen.

Table 9: Investment amount and probable generation deployment for the false solutions, solar, and wind technology

Technologies	Investment per MW of Generation (Crore BDT)	Alternate energy generation (MW)
Solar	5.6	2654
Wind	20.1	739

Source: IEPMP and authors' calculation.

7.3.2 Employment generation from Renewable Energy

Since the technologies will be run by co-firing during the operational phase, it can be assumed that no new employment creation will take place. According to Moazzem and Mashfiq (2023) for the deployment of renewable energy, per MW generates 1.94 employment. So, from the 3393 MW, 58,123 new employments could be generated. In other words, investment in so-called advanced technologies could deprive the generation of 6582 employments in the country.

7.3.3 Deprivation of other social sectors

As the power and energy sector is the recipient of the highest subsidy allocation. In FY2024, the power sector solely received 38 per cent of the total national subsidy. In the national budget FY2023-24, a total of BDT 32,000 crore has been allocated as a subsidy for the power and energy sector. In other words, the power sector uses a subsidy of BDT 1.17 crore per MW of capacity in the country. This high sectoral subsidy allocation results in depriving other sectors that are in more need of fiscal support. The allocation has increased rapidly and will continue to surge in the future in light of the financial cost estimations to deploy such expensive technologies to generate power as it may require hefty subsidy allocation. The ministry is already trying to phase out the sectoral subsidy, adding up more financial burden with further slowing down the subsidy phase-out process. Just by allocating the public expenditure required for generating 1300 MW of electricity by ammonia co-firing at least 9.6 per cent of the health sector budget and 3.5 per cent of the education budget of FY2023-24 can be increased. The amount required for deploying hydrogen co-fired will amplify the health budget by as much as 15 per cent and the education budget by 5 per cent.

8. A COST-BENEFIT ANALYSIS OF UTILISING SO-CALLED 'ADVANCED TECHNOLOGIES' IN THE POWER SECTOR: ENVIRONMENTAL-FINANCIAL-SOCIAL ASPECTS

The cost of deploying the advanced technology in Bangladesh has been estimated in three steps. First is determining the environmental cost of hydrogen and ammonia in terms of emission reduction and addition. Followed by estimating the financial cost required to reduce carbon emissions by reducing gas and coal and replacing it with hydrogen and ammonia. Lastly, the social impact of the financial cost in terms of renewable energy deployments, employment generation, and other indicators.

Environmentally, CCS offers a significant reduction in CO_2 emissions, crucial for meeting global climate targets and reducing the impact of global warming. However, the financial aspect presents challenges, as the initial investment and operational costs of CCS technology are substantial, raising questions about its economic feasibility, especially compared to renewable energy sources. On the social front, CCS technology can ensure the continued use of fossil fuels in a cleaner manner, preserving jobs in traditional energy sectors and enabling a smoother transition to a low-carbon economy. Yet, there are concerns about the long-term storage of CO_2 and potential risks, which could affect public acceptance and trust. Thus, the deployment of CCS as an advanced technology in the power sector necessitates a balanced approach, considering its ability to contribute to climate change mitigation while addressing financial constraints and fostering social acceptance.

The estimated total emission in case of co-firing hydrogen with CCGT will be 5,985,000 tonnes. It is to be noted that the hefty amount is only considering the usage of hydrogen to generate electricity from it and does not include the lifetime emission as it is assumed in IEPMP that hydrogen will be imported. On the other hand, during the 7 years, only 60,795 tonnes will be reduced, which is merely 1 per cent of the total hydrogen co-firing emission. The next question is at what cost does the IEPMP plans to reduce the 1 per cent emission? As the cost of hydrogen co-fired power generation will be BDT 5673.22 crore in 2041 for the generation capacity of 1600 MW, it is to be said that the financial cost of that 1 per cent emission reduction is BDT 5673.22 crore.

Similarly, in the case of ammonia cofiring with coal, approximately 519 tonnes CO_2 emission will be reduced annually. Hence, in 11 years, the total emission reduction will be 5709 tonnes by generating 1600 MW from ammonia co-fired. The total investment to deploy to generate 1300 MW from the ammonia will be BDT 3,685.37 crore in 2030. Once again, the financial cost compared to the environmental benefit is much higher, indicating that adopting ammonia and hydrogen-cofired power generation is a false solution for the energy transition in Bangladesh.

The last piece of this costing puzzle is the social opportunity cost of investing such a hefty amount for hydrogen and ammonia-based power generation. With the equivalent amount of total investment for hydrogen and ammonia, 29139.1 MW of solar energy and 821.1 MW of wind energy can be deployed. A total of 29,960 MW from renewable energy can easily fulfil the 40 per cent (24000 MW) renewable energy target of Bangladesh. The renewable energy deployment can end up generating 58123 new employments.

The other social priority sectors such as the health and education sector are being deprived of the fiscal assistance that they need.

By allocating the public expenditure required for generating electricity from ammonia and hydrogen co-firing at least 24.6 per cent of the health sector budget and 8.5 per cent of the education budget of FY2023-24 can be increased. The allocations of these sectors can be increased by transferring the financial resources to the health and education sector despite deploying hydrogen and ammonia with such high costs. The fiscal allocation of these social sectors can be increased from 5 per cent to as high as 15 per cent in the national budget.

9. CONCLUSION

The Ministry of Power, Energy and Mineral Resources (MoPEMR) is planning to adopt hydrogen and ammonia along with carbon capture units and nuclear as clean energy and attain the 40 per cent clean energy goal by 2041. However, globally fossil hydrogen, known as grey and blue hydrogen, and fossil ammonia, known as grey and blue ammonia have not yet proved to be efficient for carbon emission reduction. Hydrogen and ammonia from renewable sources are the ones that emit zero carbon, and zero nitrogen oxides can help achieve net zero emission targets.

The study shows that in Bangladesh the emission reduction by co-firing hydrogen and ammonia with gas and coal is negligible. However, the financial cost and implication of advanced technologies are very high indicating that these technologies are still very expensive for Bangladesh's economy to carry. The decision to adopt hydrogen and ammonia for generating electricity will be costlier than to be beneficial for the energy transition. Additionally, it will also create an additional financial burden to the existing one further depriving the other sector in need. It is not financially reasonable and economically viable for Bangladesh to go for the advanced technologies for power generation in 2035. Adopting renewable energy-based hydrogen and ammonia fuel cells or renewable energy fuel cells if they become cheap and less expensive in the future can be considered.

Instead, the financial resources should be used to generate electricity from traditional renewable energy sources and attain 40 per cent from renewable energy by 2041. Opting to generate electricity from renewables will not only help Bangladesh to achieve its energy transition goals but also help generate employment on a high scale. Moreover, the stance on advanced technologies mentioned in the IEPMP needs to be assessed and revised accordingly. Instead of going for false solutions by starting hydrogen and ammonia co-firing, all the focus should be on deploying renewable energy in the medium to short-term.

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