Authors:
M Srinivas (DGM/NTPC Ltd)
RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)

# GREEN AMMONIA CO-FIRING: Pathway to Decarbonize Thermal Power Generation

## ABSTRACT

This paper explores the implementation of green ammonia co-firing in Thermal Power plants, focusing on its feasibility, benefits, and roadmap. Green ammonia is an innovative solution for decarbonizing thermal power plants by reducing greenhouse gas (GHG) emissions and promoting renewable energy integration. This study aligns with India's commitment to achieving net-zero emissions by 2070 and highlights the technological, economic, and environmental dimensions of the proposed pilot project.

## INTRODUCTION

The increasing urgency of climate change demands a transition from carbon-intensive energy sources to cleaner alternatives. India, as a signatory to the Paris Agreement, has pledged to reduce its carbon intensity by 45% by 2030 and achieve net-zero emissions by 2070. The power sector, contributing the largest share of India's CO2 emissions, plays a pivotal role in this transition.

Green ammonia, produced using renewable energy, offers a promising avenue for decarbonization and co-firing aims to reduce the carbon footprint while leveraging existing infrastructure, in a thermal power base. This paper examines the feasibility and implications of adopting green ammonia in coal-based thermal power plants.

Authors:
M Srinivas (DGM/NTPC Ltd)
RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)

*Global and Indian Energy Landscape*

Globally, the average per capita GHG emissions stand at 6.3 tCO2e, while India's emissions are significantly lower at 2.4 tCO2e. However, India's absolute emissions are substantial due to its large population and dependence on coal, which constitutes 51% of the installed power capacity.

India's Nationally Determined Contributions (NDCs) include:

- Achieving 50% of installed capacity from non-fossil sources by 2030.
- Reducing carbon intensity by 45% compared to 2005 levels by 2030.
- Achieving net-zero emissions by 2070.

These commitments underline the importance of transitioning to renewable energy sources and integrating innovative technologies like green ammonia co-firing.

**WHY GREEN AMMONIA?**

Green ammonia is synthesized using hydrogen from water electrolysis and nitrogen from air separation, powered by renewable energy. Unlike grey ammonia, which emits approx 2 tons of CO2 per ton of production, green ammonia is carbon-neutral and produces almost NIL CO2 during generation. Some key advantages include:

1. **Environmental Benefits**: Zero CO2 emissions align with decarbonization efforts.
2. **Regulatory Compliance**: Favorable carbon taxes and enhanced ESG ratings.
3. **Economic Viability**: Long-term cost efficiency as renewable energy prices decline.
4. **Multi-sectoral Applications**: Usability in agriculture, shipping, and energy storage.

This image below illustrates a multi-stage action plan for decarbonizing thermal power plants. Stage 0 focuses on operational improvements and equipment retrofits, achieving

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Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)

initial reductions in CO2 emissions. Stage 1 introduces biomass co-firing and enhancements like higher efficiency from steam temperature rise, further reducing emissions by approximately 10%. Stage 2 involves the integration of advanced technologies like ammonia and hydrogen co-firing, targeting an additional 10% reduction in emissions. The goal is to achieve significant CO2 emission reductions, transitioning towards sustainability and achieving emissions below 500 gm CO2/kWh.

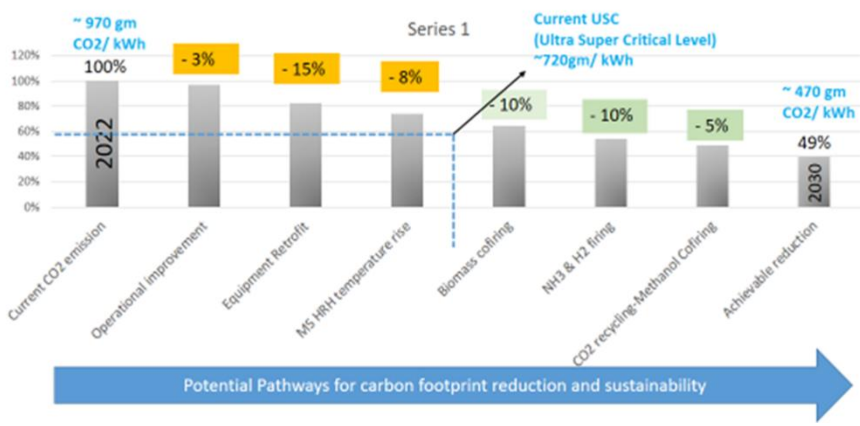



*Figure 1 Multi-Stage action plan for Decarbonisation*

Authors:
M Srinivas (DGM/NTPC Ltd)
RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)

## SWOT ANALYSIS FOR GREEN AMMONIA CO-FIRING IN THERMAL POWER PLANTS

Co-firing green ammonia in thermal power plants presents a mixed landscape of strengths, weaknesses, opportunities, and threats. Among the strengths is the potential to leverage existing infrastructure and expertise in the energy sector to transition toward cleaner energy solutions. Thermal power plants often have the necessary land and resources to integrate green ammonia, and strong financial backing from stakeholders can further facilitate this transition. However, the challenges include limited experience with green ammonia technologies and the high initial costs associated with infrastructure upgrades and implementation. The technology readiness level is relatively low, which presents a barrier to seamless adoption.

On the other hand, significant opportunities exist in being an early adopter of green ammonia co-firing, which could position entities as leaders in energy transition. The ability to tap into the carbon trading market and enhance public image through environmental, social, and governance (ESG) initiatives adds further appeal. This approach also aligns with global efforts to catalyze the shift from fossil fuels to greener alternatives. However, potential threats include high production costs of green ammonia, stakeholder resistance to change, policy uncertainty, and the risk of technological disruption. These factors must be carefully managed to ensure the successful integration of green ammonia into the energy mix.

Authors:
M Srinivas (DGM/NTPC Ltd)
RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)

## TECHNICAL FEASIBILITY OF GREEN AMMONIA CO-FIRING

Green ammonia's technical feasibility in thermal power plants as a co-firing fuel is influenced by its properties, integration challenges, and emission reduction potential.

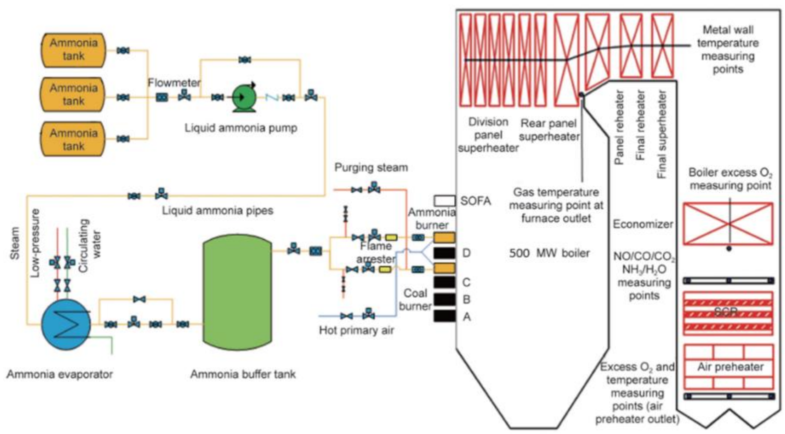



*Figure 2 General Layout of Co-Fired Boiler*

Some critical insights w.r.t technical feasibility include:

***Combustion Compatibility****:*

Studies demonstrate that co-firing ammonia with coal up to 20% is technically feasible without significant modifications to boiler efficiency. Experimental setups confirm stable combustion characteristics, even at higher ammonia co-firing ratios. Modifications required include ammonia injection systems, optimized nozzle designs, burner front modifications and selective catalytic reduction (SCR) units to address NOx emissions

Authors:
M Srinivas (DGM/NTPC Ltd)
RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)

*Emission Characteristics:*

Ammonia co-firing significantly reduces CO2 emissions compared to coal combustion. However, it introduces challenges with nitrogen oxide (NOx) emissions. Advanced SCR systems or staged combustion are necessary to mitigate NOx.

Life Cycle Analysis (LCA) indicates that green ammonia offers the lowest greenhouse gas emissions (1062 kg CO2e/MWh) compared to blue and gray ammonia

*Energy Efficiency:*

Co-firing reduces boiler efficiency by only about 1% compared to baseline coal plants, whereas CCS integration reduces it by approximately 8% due to the energy-intensive CO2 capture process

*Infrastructure Requirements:*

Existing coal-fired plants require modifications to store, transport, and inject ammonia. Storage systems for ammonia must maintain it at -33°C and ambient pressure to ensure safety and efficiency.

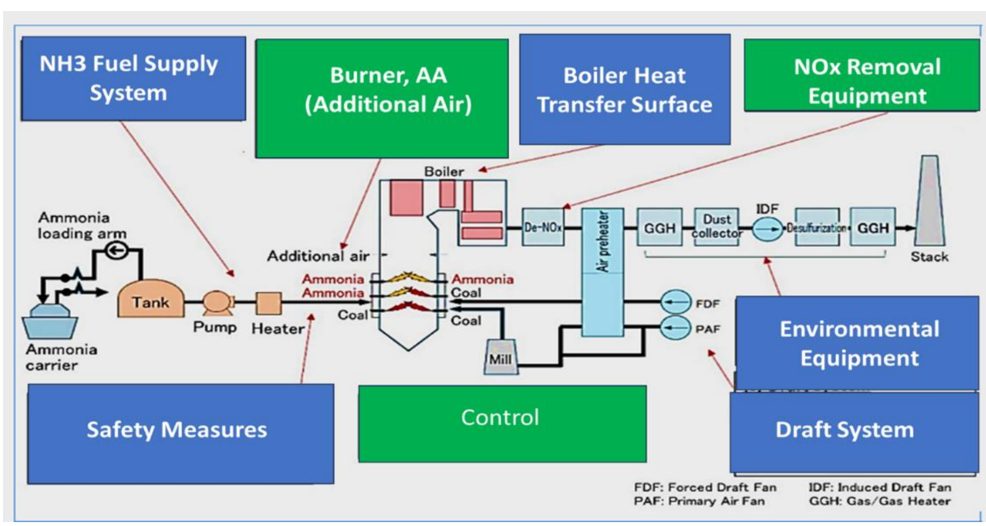



*Figure 3 Major System modifications*

Authors:
M Srinivas (DGM/NTPC Ltd) RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd) P Krishna Kishore (Manager/NTPC Ltd)

*NOx Emission Control:*

Experiments show that using staged combustion and SCR systems can reduce NOx levels to acceptable limits, even with high ammonia co-firing ratios. Further research into optimal injection techniques and SCR designs can ensure compliance with emission regulations

*Scalability and Integration:*

Globally, ammonia infrastructure exists primarily for fertilizers, requiring adaptation for energy applications. Integration into existing plants is faster and less complex than deploying CCS, providing an advantage for near-term decarbonization

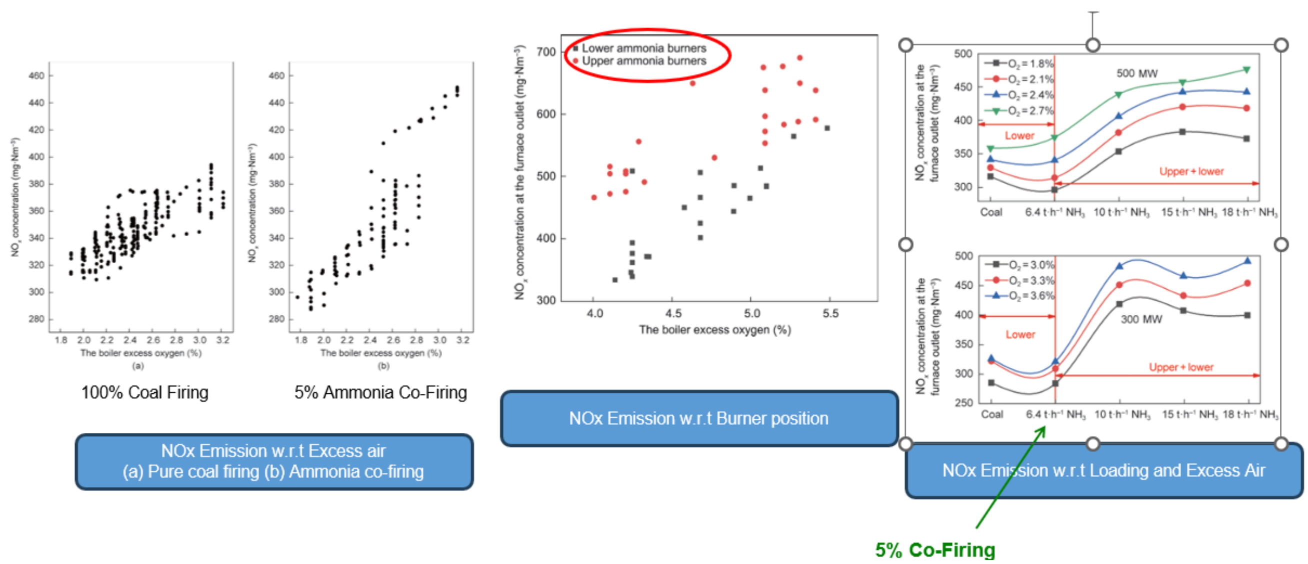



*Figure 4 Effect of Co-Firing on NOx emission*

Authors:
M Srinivas (DGM/NTPC Ltd)
RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)

***Technical Challenges for co-firing ammonia in existing coal based TPPs***

1. *Ammonia Slip and Toxicity:*
    a. Unburned ammonia (ammonia slip) can lead to safety and environmental concerns. Improved combustion techniques and SCR systems can address these issues.
2. *Storage and Transportation:*
    a. Safe storage and handling are critical due to ammonia's toxicity and flammability. Expanding infrastructure for large-scale ammonia use in power plants requires significant investment
3. *Cost of Green Ammonia:*
    a. Current production costs of green ammonia are high ($666/tonne), driven by the cost of renewable electricity. Scaling production and reducing renewable energy costs are necessary to enhance feasibility.

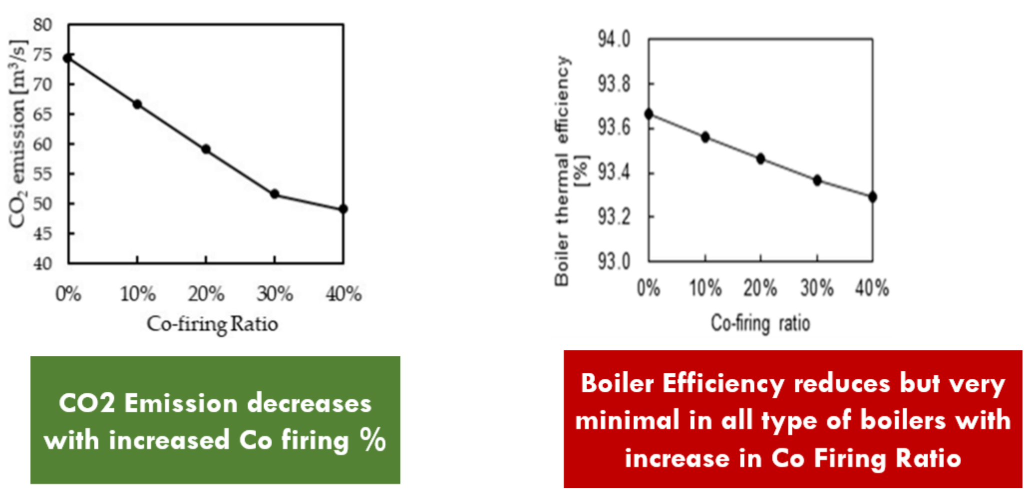



*Figure 5 Effect of Co-firing on COx emission and Boiler efficiency.*

The technical feasibility of green ammonia for co-firing in thermal power plants is well-supported by existing research and pilot projects. It offers a promising pathway for decarbonization when paired with appropriate emission control measures and cost reduction strategies. While challenges related to NOx emissions, storage, and production costs remain, ongoing advancements in ammonia combustion technologies and green ammonia production hold the potential to make this a viable and scalable solution for decarbonizing the energy sector.

**TEAM GREEN FUSION- PILOT PROJECT**

We propose a pilot project to implement green ammonia co-firing as a sustainable energy solution, to support decarbonization in the Indian energy sector. The project aims to integrate renewable energy sources, such as solar and wind, to power an electrolyzer that produces green hydrogen (H2). An air separation unit (ASU) will extract nitrogen (N2) from the atmosphere, which, when combined with green hydrogen, will synthesize green ammonia (NH3) in an environmentally friendly ammonia synthesis unit. The produced green ammonia will be stored in a dedicated facility and subsequently utilized for co-firing in boilers to replace conventional fuels. This approach not only reduces greenhouse gas emissions but also paves the way for integrating renewable energy into existing infrastructure. Our proposal seeks to validate the technical feasibility, economic viability, and environmental benefits of green ammonia co-firing and positioning it as a scalable solution.

Authors:
M Srinivas (DGM/NTPC Ltd) RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd) P Krishna Kishore (Manager/NTPC Ltd)

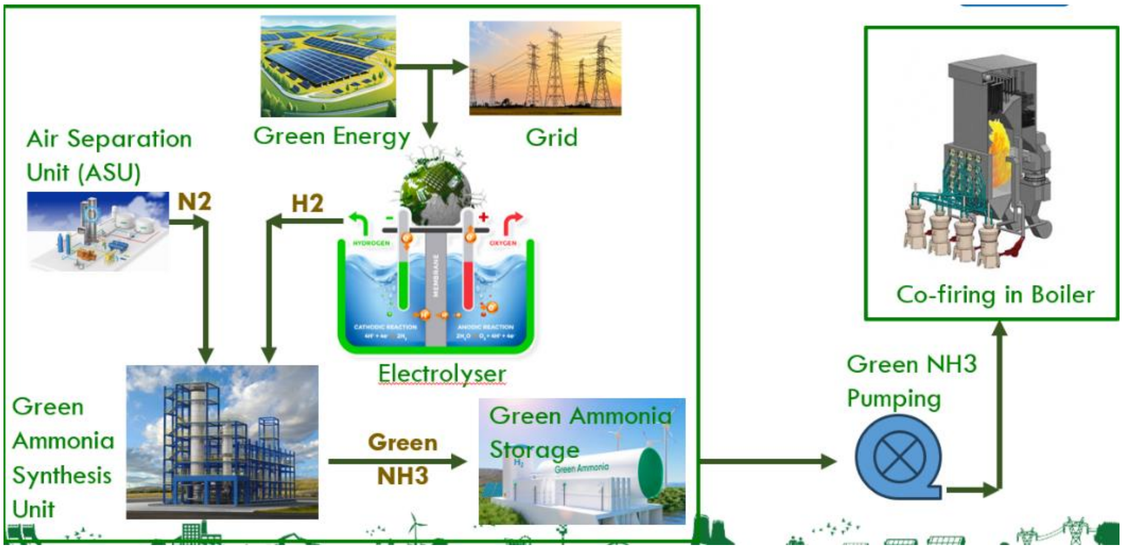



*Figure 6 Overview of G-NH3 production*

**PROJECT PLANNING**

Our proposal outlines a comprehensive pilot project for green ammonia production and co-firing in boilers. The project involves key packages such as power supply through renewable energy integration, green hydrogen production via electrolysis, and nitrogen extraction using an air separation unit (ASU). The synthesized green ammonia will be stored and subsequently utilized for co-firing in boilers, reducing reliance on conventional fossil fuels. Additionally, the proposal includes support systems like cooling, water treatment, and wastewater management to ensure operational efficiency. This initiative demonstrates a scalable pathway for leveraging renewable energy while minimizing carbon emissions, aligning with global sustainability goals.

Building upon our proposal, the detailed layout for the proposed Green Ammonia Production Unit spans 125 acres, segmented into key functional areas. The facility will feature a Green Ammonia Synthesis unit with a production capacity of 1900 TPD, a Green Hydrogen production plant with a capacity of 350 TPD, and an Air Separation Unit (ASU) for nitrogen extraction, occupying allocated zones of 50-60 acres, 30-35 acres, and 10-15 acres

Authors:
M Srinivas (DGM/NTPC Ltd) RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd) P Krishna Kishore (Manager/NTPC Ltd)

respectively. Additionally, 10-15 acres are dedicated to switchyards and substations, ensuring uninterrupted energy supply and grid integration. The plan also includes a 30-acre green belt for environmental sustainability and a 20-acre industrial area for administrative buildings, workshops, and dedicated stores.

The inclusion of a green belt ensures ecological balance, while the industrial area supports operational excellence and project management. This comprehensive layout reflects a well-planned initiative, paving the way for green ammonia as a clean energy solution.

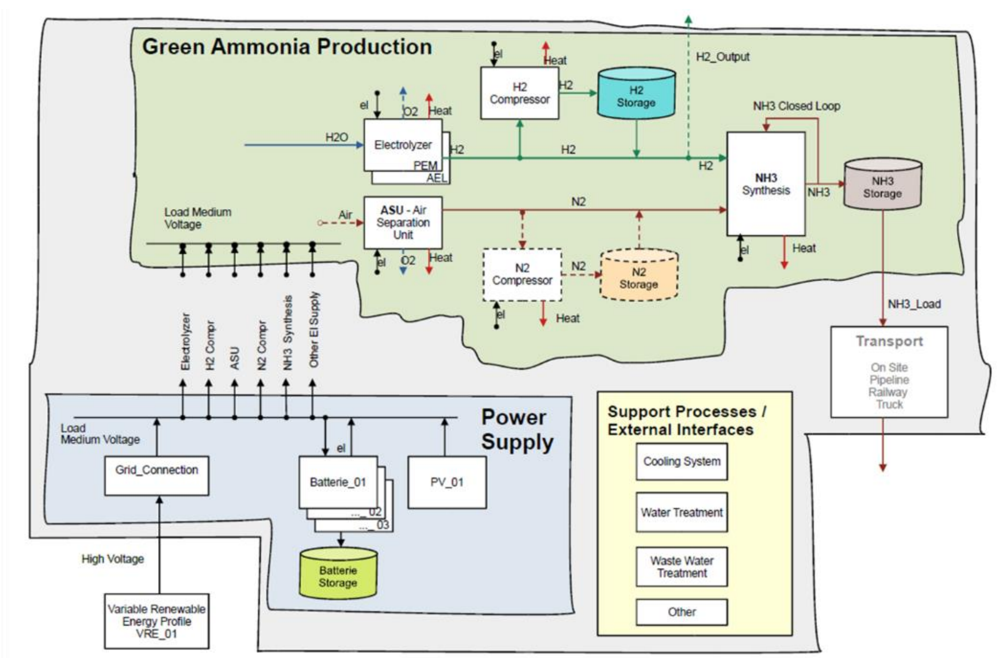



*Figure 7 Work Packages in Green Ammonia Production*

This image outlines a phased approach for the implementation of a green ammonia production unit, detailing production capacities, infrastructure development, and funding strategies. The project is divided into three phases:

Authors:
M Srinivas (DGM/NTPC Ltd)
RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)

1. **Phase I** focuses on preparatory activities such as tendering, engineering designs, and initial civil works like land development, road construction, and 50% industrial shed setup. Electrical requirements are limited to construction power.
2. **Phase II** scales production with 150 TPD of green hydrogen and 850 TPD of green ammonia. It also involves infrastructure enhancements, such as completing the central business district and water systems, while adding burner modifications and electrical switchyard installations.
3. **Phase III** mirrors Phase II's production output but emphasizes the completion of civil works, including water treatment systems and remaining infrastructure.

Funding is sourced from equity, government subsidies, and debt arrangements, with potential revenue from carbon tax savings, carbon credits, and ESG improvements. This structured approach ensures gradual scaling with financial and operational feasibility.

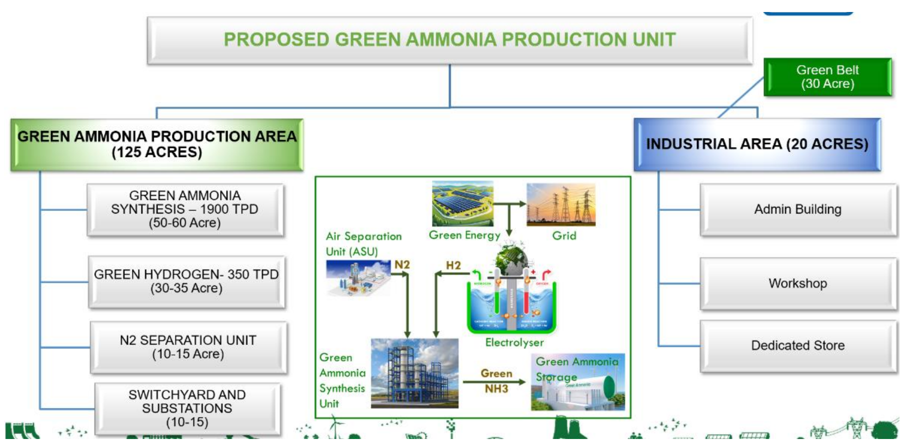



*Figure 8 Area Division of proposed unit*

This table below provides a detailed cost breakdown for the proposed green ammonia production project across three phases, totaling INR 12,400 crores. The major expenditures include land acquisition, infrastructure development (roads, drainage, industrial sheds), power infrastructure, and pre-operative expenses. The phased approach ensures a structured allocation of resources for sustainable implementation.

| Component | Phase I (in Crs) | Phase II (in Crs) | Phase III (in Crs) |
|---|---|---|---|
| Land (Purchase) & registration | 180 | 60 | 40 |
| Site Development | 143 | 0 | 0 |
| Roads & Drainage | 57.2 | 28.6 | 0 |
| Cost of Street Lights | 5.72 | 5.72 | 0 |
| Water Supply System | 85.8 | 85.8 | 0 |
| Industrial Sheds, Admin Block Etc | 2002 | 1830.4 | 0 |
| DM Plant | 0 | 57.2 | 0 |
| Conveying Systems | 0 | 114.4 | 114.4 |
| Power Infra for Industrial Cluster | 314.6 | 2917.2 | 2934.36 |
| Power Transmission Lines | 57.2 | 57.2 | 0 |
| Contingency | 286 | 286 | 114.4 |
| Pre-operative expenses (Consultancy, Financing Costs etc.) | 200.2 | 429 | 248.36 |
| Total | 3180.32 | 5811.52 | 3411.52 |
| **Grand Total (INR in Crs)** | **12,403.36** | | |

*Figure 9 Capex Split-up*

The pilot project's capital expenditure includes the cost of electrolyzers, air separation units, and ammonia synthesis and storage facilities. The phased investment plan ensures gradual scalability. Key financial insights include:

- Green ammonia costs are expected to decrease to INR 70/kg by 2035.
- Savings from reduced coal consumption and carbon taxes savings
- Revenue streams include carbon credits and improved ESG scores.

Authors:
M Srinivas (DGM/NTPC Ltd) RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd) P Krishna Kishore (Manager/NTPC Ltd)

**GREEN FUSION BUSINESS MODEL- Analysis of Operational and Financial Parameters:**

Team Green fusion has developed a business model to assess the impact of various operational and financial parameters for setting up of Green Ammonia Generation unit and further Co-firing in Boilers.

Based on co-firing percentage input, the model has the capability to calculate Landed cost of Green Ammonia (LCoA), Capex required for the project, Carbon Tax Savings, Capex distribution over project life, cost of electrolysers, Varciable cost of Co-Fired plant etc. Snapshots of our model are as below:

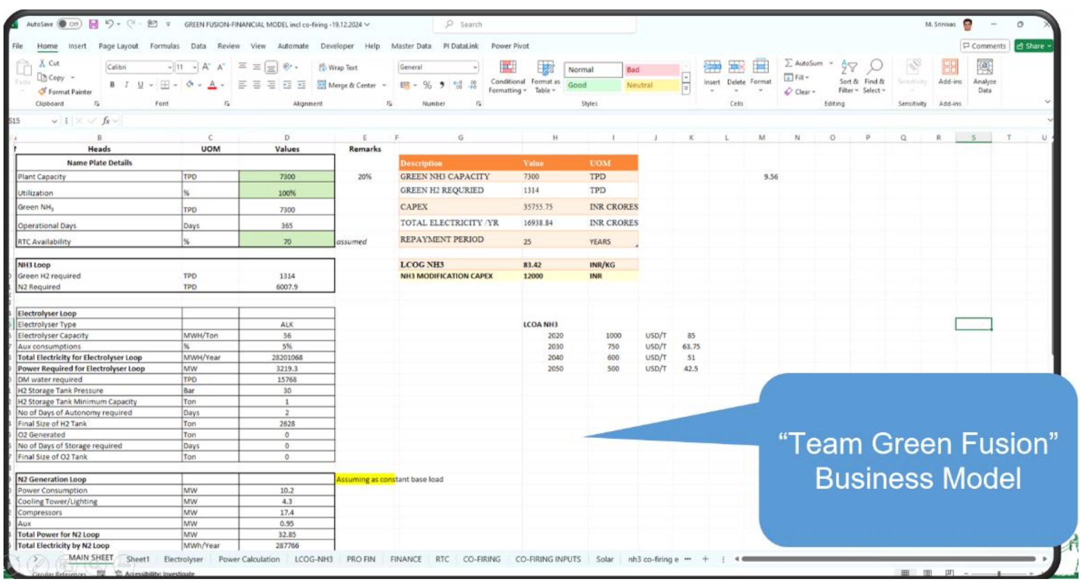
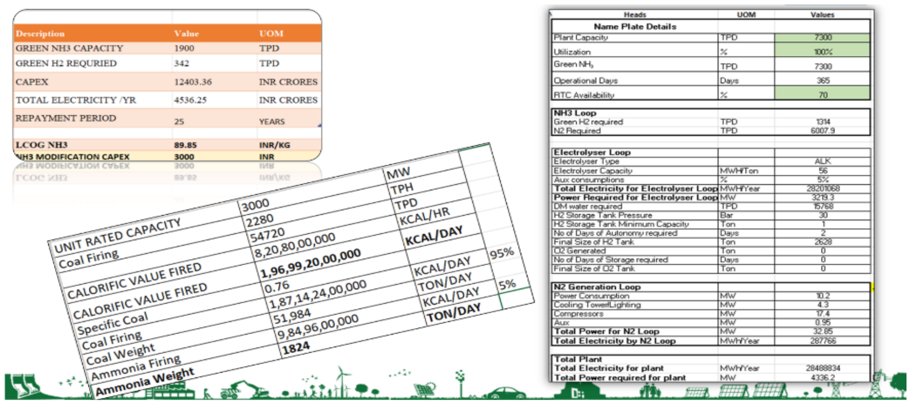



*Figure 10 Snapshot of Business Model*

Authors:
M Srinivas (DGM/NTPC Ltd)
RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)



| Description | Value | UOM |
|---|---|---|
| GREEN NH3 CAPACITY | 1900 | TPD |
| GREEN H2 REQURIED | 342 | TPD |
| CAPEX | 12403.36 | INR CRORES |
| TOTAL ELECTRICITY /YR | 4536.25 | INR CRORES |
| REPAYMENT PERIOD | 25 | YEARS |
| | | |
| LCOG NH3 | 89.85 | INR/KG |
| NH3 MODIFICATION CAPEX | 3000 | INR |

| | | | |
|---|---|---|---|
| UNIT RATED CAPACITY | 3000 | MW | |
| Coal Firing | 2280 | TPH | |
| | 54720 | TPD | |
| CALORIFIC VALUE FIRED | 8,20,80,00,000 | KCAL/HR | |
| CALORIFIC VALUE FIRED | 1,96,99,20,00,000 | KCAL/DAY | |
| Specific Coal | 0.76 | | |
| Coal Firing | 1,87,14,24,00,000 | KCAL/DAY | 95% |
| Coal Weight | 51,984 | TON/DAY | |
| Ammonia Firing | 9,84,96,00,000 | KCAL/DAY | 5% |
| Ammonia Weight | 1824 | TON/DAY | |

| Heads | UOM | Values |
|---|---|---|
| Name Plate Details | | |
| Plant Capacity | TPD | 7300 |
| Utilization | % | 100% |
| Green $NH_3$ | TPD | 7300 |
| Operational Days | Days | 365 |
| RTC Availability | % | 70 |
| NH3 Loop | | |
| Green H2 required | TPD | 1314 |
| N2 Required | TPD | 6007.9 |
| Electrolyser Loop | | |
| Electrolyser Type | | ALK |
| Electrolyser Capacity | MWH/Ton | 56 |
| Aux consumptions | % | 5% |
| Total Electricity for Electrolyser Loop | MWH/Year | 28201068 |
| Power Required for Electrolyser Loop | MW | 3219.3 |
| DM water required | TPD | 15768 |
| H2 Storage Tank Pressure | Bar | 30 |
| H2 Storage Tank Minimum Capacity | Ton | 1 |
| No of Days of Autonomy required | Days | 2 |
| Final Size of H2 Tank | Ton | 2628 |
| O2 Generated | Ton | 0 |
| No of Days of Storage required | Days | 0 |
| Final Size of O2 Tank | Ton | 0 |
| N2 Generation Loop | | |
| Power Consumption | MW | 10.2 |
| Cooling Tower/Lighting | MW | 4.3 |
| Compressors | MW | 17.4 |
| Aux | MW | 0.95 |
| Total Power for N2 Loop | MW | 32.85 |
| Total Electricity by N2 Loop | MWh/Year | 287766 |
| Total Plant | | |
| Total Electricity for plant | MWh/Year | 28488834 |
| Total Power required for plant | MW | 4336.2 |

*Figure 11 Snapshots of business model*

## BUSINESS MODEL RESULTS:

a. The CAPEX breakdown: for setting up a green ammonia plant includes the major cost components such as Hydrogen (48%) and Nitrogen & Ammonia (24%), which collectively account for over 70% of the total expenditure. This implies that over next decade or so, a reduction in cost of electrolysers through technological maturity and shift in supply demand curves is necessitated, for making green ammonia production and co-firing more economical.

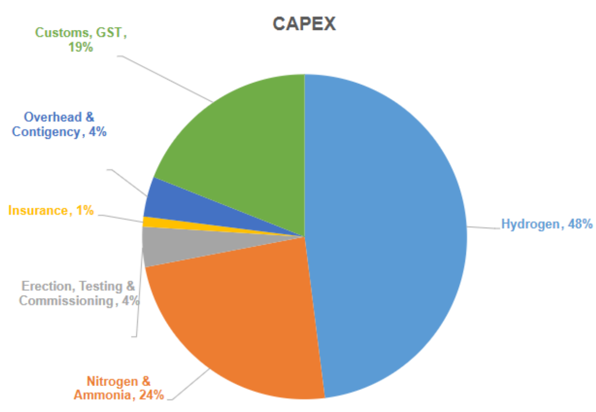



*Figure 12 Components of CAPEX*

b. Change in Variable Cost w.r.t Co-Firing Ratio: As the co-firing ration increases, the change in variable cost (i.e. VC of coal fired units – VC of co-fired units) increases. This is an obvious result, but a point can be chosen for Pilot project to balance financial impact at current prices.

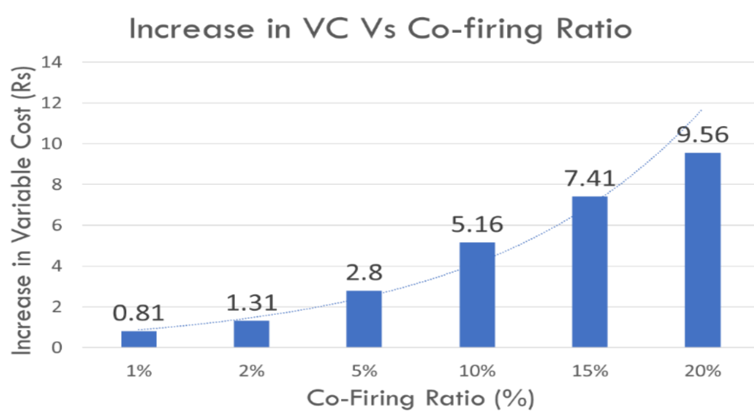



*Figure 13 Co-firing ratio vs Variable cost*

c. Over the next decades, as the cost of production of Green Ammonia decreases mainly due to reduction in cost of Electrolysers, technological penetration, shifting supply demand economics, and scalable projects, the Variable cost of co-fired units is expected to come down in similar fashion.

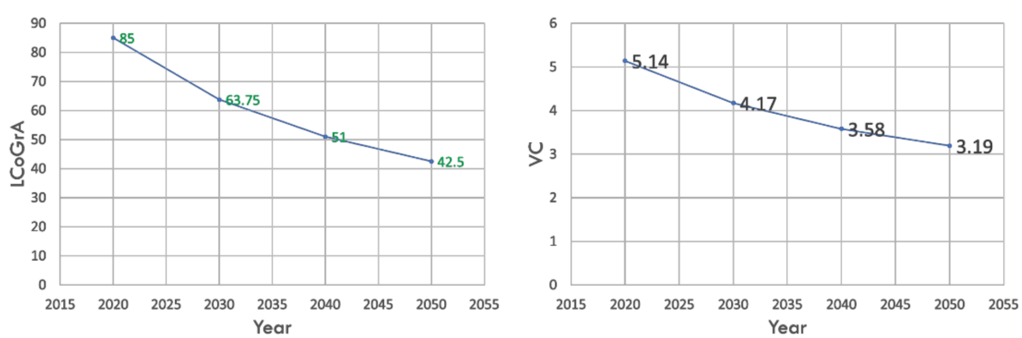



*Figure 14 Change in LCoA and VC over next decades*

d. The image below is a derivative of Green Fusion Business model, wherein it can be seen that with the increase in co-firing ratio, the Savings on account of Carbon tax is also reduced and with 20% co-firing, it stands at greater than 50 Lakhs per day.

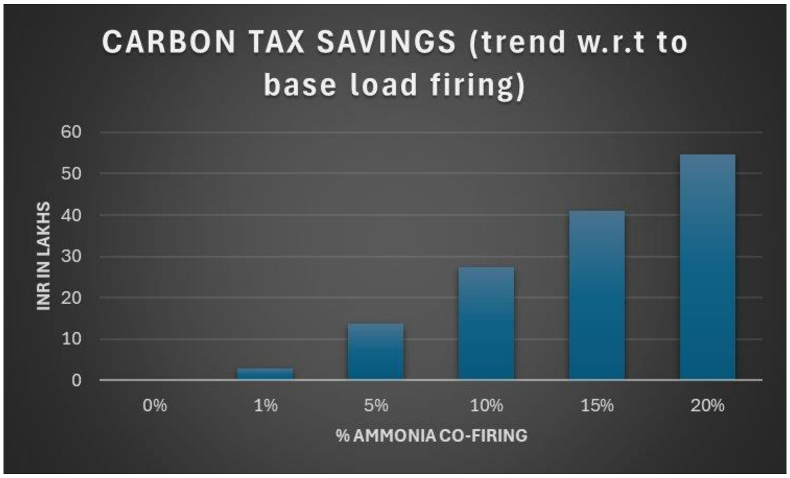



*Figure 15 Proposed daily savings in Carbon tax*

e. The table is primarily the effect of expected fall in electrolyser prices over the next decade and its impact on Capex for Ammonia production plant set-up.

| | 5% co-firing | | | 20% co-firing | |
|---|---|---|---|---|---|
| **Parameter** | **Value 2024** | **Value 2035** | **Unit** | **Value 2024** | **Value 2035** |
| Capacity of Ammonia Plant | 1900 | 1900 | TPD | 7300 | 7300 |
| % Co-Firing design | 5 | 5 | % | 20 | 20 |
| Capital Cost [excl Land] | **12500** | **7200** | INR Cr | 34300 | 14400 |
| Levelized cost of Green $NH_3$ | 89.85 | 78.36 | INR/kg of $NH_3$ | 82.61 | 71.07 |
| Increase in Variable Cost of Electricity | 2.77 | | Rs/KWH | 9.46 | |

*Figure 16 Effect of project reduction in Cost of Electrolysers*

Authors:
M Srinivas (DGM/NTPC Ltd)
RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)

**Phase 1: Planning and Feasibility (2025-2028)**

- **Feasibility Study:**
  - Conduct detailed feasibility studies for establishing green ammonia plants.
  - Evaluate technological, environmental, and economic aspects.
- **Collaborations and MOUs:**
  - Establish partnerships with renewable energy providers and international technology leaders.
  - Draft agreements for raw materials, renewable energy requirements, and co-firing technology support.
- **Regulatory Framework:**
  - Engage with government bodies to establish regulatory frameworks for green ammonia production and usage.
  - Pursue policy-level support for carbon credit systems and incentives.

## Phase 2: Pilot Project and Demonstration (2028-2030)

- **Pilot Plant Setup:**
  - Commission a pilot green ammonia production facility integrated with renewable energy sources like solar or wind.
  - Test the co-firing capability of ammonia in existing thermal power plants.
- **Demonstration and Analysis:**
  - Conduct 5% co-firing trials and analyze the results.
  - Assess CO2 emission reductions, impact on plant efficiency, and operating costs.

- **Stakeholder Engagement:**
  - Share results with stakeholders, including policymakers, industry experts, and investors, to build support for scaling up.

## Phase 3: Scale-Up and Deployment (2030-2035)

- **Expanded Co-Firing:**
  - Gradually increase co-firing percentage to 10% and later to 20% based on pilot results.
  - Modify plant infrastructure as necessary to handle higher ammonia co-firing rates.
- **Horizontal Deployment:**
  - Deploy green ammonia co-firing capabilities across multiple plants.
  - Establish logistical networks for ammonia transportation and storage.

## Phase 4: Full Integration and Market Expansion (2035-2050)

- **100% Co-Firing:**
  - Aim for full integration of ammonia co-firing in thermal power plants.
  - Retrofit plants to accommodate ammonia as the primary fuel.
- **Green Hydrogen Ecosystem:**
  - Integrate green hydrogen production with green ammonia plants.
  - Develop related industries, such as fertilizer production and hydrogen fuel applications.
- **Global Market Expansion:**
  - Export surplus green ammonia and related technologies to emerging markets and establish a leadership position in green ammonia and hydrogen technologies.

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M Srinivas (DGM/NTPC Ltd)
RV Kiran (Sr. Mgr/NTPC Ltd)
Rohan Kr. Sabat (Manager/NTPC Ltd)
P Krishna Kishore (Manager/NTPC Ltd)

## Key Outcomes

- **Environmental Impact:**
  - Significant reductions in CO2 emissions.
  - Reduction in coal consumption and ash generation.
- **Economic Viability:**
  - Development of a sustainable business model through government incentives and carbon credits.
- **Technology Leadership:**
  - Establishing advanced, eco-friendly energy systems that pave the way for a green future.

### CONCLUSION AND FUTURE OUTLOOK

Green ammonia co-firing represents a critical step in India's energy transition journey. While challenges persist, the long-term benefits of reduced emissions, economic savings, and alignment with national goals outweigh the hurdles. By leveraging technological innovations and strategic partnerships, thermal power plants can integrate green ammonia into India's power sector. Future research should focus on scaling the technology, enhancing cost efficiency, and ensuring stakeholder engagement.

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P Krishna Kishore (Manager/NTPC Ltd)

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