भारत सरकार
Government of India
केन्द्रीय विद्युत प्राधिकरण
Central Electricity Authority
स्वच्छ ऊर्जा एवं ऊर्जा पार गमन प्रभाग
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File No. CEA-PL-12-50/1/2024-CEET/ Date: 05.08.2024

Subject: Inputs on "Base Paper on Application of Green Ammonia Co-firing in Coal and Gas fired Thermal Power Plants" prepared by CEA- regd.

Sir/Madam,

Decarbonization of power sector is an essential component to achieve Net zero emission i.e. NZE target by 2070. However, with more than 50% installed capacity of Thermal sources (i.e. coal, lignite, and gas) and 70% energy contribution makes India totally reliant on Thermal energy. As per updated NDC to Paris Agreement, India is committed reduce Emissions Intensity of its GDP by 45 percent by 2030, from 2005 level. Under such circumstances, India is exploring various strategies to reduce carbon emissions from thermal power generation. These include carbon capture utilization and storage (CCUS), Biomass co-firing, Ammonia co-firing and substituting natural gas with alternative gases like green hydrogen or bio-methane. Ammonia co-firing especially green ammonia can be one of the promising alternatives. Ammonia co-firing is like Ammonia blending with coal which will reduce CO_2 emission in proportionate ratio due to no carbon content in Ammonia.

2. CEA is preparing a study to explore the impact of various policies and technology interventions to reduce the CO_2 emissions from Coal based TPPs. In line of the above study, a base paper on Application of Green Ammonia Co-firing in Gas as well as Coal fired TPPs is prepared by CEA (***copy enclosed***). This base paper explores the possibility of ammonia co-firing in new/existing coal-fired as well as gas based power plants and its impact on cost which in turn result in efforts towards decarbonizing India's power generation.

3. In this regard, valuable inputs/comments/views of Stakeholders which includes Government bodies, Power utilities, Industries, Supply vendors, EPC contractors, Technology providers, Academia and others on the enclosed base paper are solicited.

4. Please share your inputs on the paper along with technical paper/feasibility study, if any, carried out for Ammonia (NH_3) co-firing in gas as well as coal based TPPs. This paper may also be shared with other stakeholder for inputs

5. **It is therefore requested to provide your valuable inputs on following email id:**

ceet-cea@gov.in .

Encl.: As Above

5.8.24

(Vijay Menghani)
Chief Engineer (CE&ET)

To,

List of Stakeholders (as *attached*)

Copy to: With the request to give their valuable suggestions and inputs
1. Members (Planning/Thermal/Hydro/GO&D/Power System/E&C), PCE-I/PCE-II, CEA

List of key Stakeholders

1. Programme Director (Energy Vertical), Niti Aayog
2. JS (Climate Change), MoEF&CC
3. CMD NTPC, NTPC NETRA, NTPC (Energy Transition and Policy Research)
5. CMD, THDC
6. CMD, NLCIL
7. Chairman, DVC
8. CMD, SJVNL
9. MD&CEO, Adani Power Ltd.
10. Chairman, APGENCO
11. CEO, Bajaj Energy
12. CEO, GMR
13. Managing Director, GSECL
14. Managing Director, HPGCL
15. MD&CEO, JSW Energy Ltd.
16. CMD, MAHAGENCO
17. Managing Director, MPPGCL
18. CMD, NEEPCO
19. CEO, Reliance Energy Limited
20. CMD, RRVUNL
21. MD&CEO, Tata Power Company Limited
22. Chairman, TANTRANSCO
23. Managing Director, Torrent Power Ltd.
24. CMD, TSGENCO
25. Chairman, UPRVUNL
26. CMD, WBPDCL
27. CMD, BHEL
28. CEO, Thermax Limited India
29. CMD, L&T India Ltd.
30. CEO&MD, Greenko group
31. CEO, Dastur Energy
32. CMD, Mitsubishi Power India Private Limited
33. Director General, CPRI
34. Director General, NPTI
35. Director, IIT Delhi
36. Director, IIT Kanpur
37. Director, IIT Bombay
38. Vice Chancellor, DTU

Draft Base Paper
Application of Green Ammonia Cofiring in TPPs

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This base paper is basically exploring the possibility of green ammonia co-firing in new/existing coal-fired as well as gas based power plants – an efforts towards limiting global warming to 1.5°/2°C and achieving India's net zero by 2070.

1. Introduction:

Presently, India has around 242 GW thermal (coal/lignite/gas) installed capacity constituting 55% of total installed capacity (as on 30.04.2024). Further, in order to meet the base load requirement of the country in 2032, government has set target of adding additional minimum 80000 MW coal based capacity by 2031-32.

In India, coal is currently the dominant fuel for electricity generation to support rapid economic development ensuring energy security and stabilizing electricity supply. Further, coal is expected to remain as a major power source in the near term of transitioning to a low-carbon future. However, the coal power industry is also the largest CO_2 emitters, accounting for around 40% of country's carbon emissions. India has declared its goal of becoming carbon neutral by 2070. In such a circumstance, the coal power industry is under increasingly great pressure to reduce CO_2 emissions.

In this direction, the power utilities are pursuing decarbonisation technologies, such as advanced boiler technology (USC), biomass cofiring etc. Further, the low-carbon fuels such as hydrogen-containing fuels, mainly ammonia (NH_3) can be regarded as a promising option to reduce CO_2 emission by partially or fully substituting natural gas as well as cofiring with coal based TPPs.

2. Background:

The global average concentration of CO_2 in the atmosphere is around 423 ppm[1] (0.042%) as of Feb-2024. This is an increase of around 50% since the start of the Industrial Revolution, up from 280 ppm (0.028%).

India is third largest CO_2 emitter after China and USA in the world. India's CO_2 emission for the year 2019 stands at 2.64 Gigatonne (Gt) as per India's third national communication[2] to UNFCCC in Dec-2023.

It is pertinent to mention here that as per the IPCC's Climate Change 2022 (Mitigation of Climate Change) report[3]: Summary for policymakers[3] suggesting emission pathways and system transitions consistent with 1.5°C global warming indicates that historical cumulative net CO_2 emissions from 1850 to 2019 were 2400 ± 240 $GtCO_2$. The global remaining carbon budget from 2020 onwards is estimated as 500 $GtCO_2$ with a probability of 50% for limiting warming to 1.5°C, and 1150 $GtCO_2$ with a probability of 67% for limiting warming to 2°C. Carbon budget refers to the total net amount of carbon dioxide (CO_2) that can still be emitted by human activities while limiting global warming to a specified level.

Additionally, the first Global Stocktake (GST)[4] (mentioned under Article-4 of Paris agreement) concluded during COP-28 indicates that all signatories to Paris agreement should accelerate efforts towards the phase-down of unabated coal power and transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner so as to achieve net zero by 2050.

Moreover, the IEA's Net Zero Roadmap by 2050 (2023 update)[5] scenario indicates that "unabated" coal-fired power generation should be phased out by 2030 in developed economies and by 2040 in emerging market and developing economies (EMDEs). The IPCC Sixth Assessment Report[6] clearly states that "abated" refers to capturing 90% or more CO_2 from power plants.

Further, India has declared its goal of becoming carbon neutral by 2070. In order to achieve the 1.5°C/ 2°C goal and net-zero emissions by 2070 significant reductions in CO_2 must be made particularly from coal based TPPs as far as power sector is concerned.

3. Approaches for CO2 reductions:

Basically, there are two approaches which can reduce the CO_2 emission significantly from supply side. First is by increasing the RE (Solar/wind mainly) based capacity and secondly by the deployment of interventions in coal based TPPs. But due to RE variability and its reliability issues, RE alone cannot meet the demand of base load generation. Presently, Coal based TPPs provides for base load generation demand.

Considering energy security & affordability and India's self-reliance on coal production where coal is presently contributing around 73% of electricity demand, in this scenario India could not afford the phasing down of coal based TPPs. Therefore, India needs some technological interventions in coal based TPPs to reduce the CO_2 emission considering environmental commitments of the country.

As discussed above and considering IPCC definition, it can be inferred that unabated coal based power plant can become abated coal based TPPs with application of interventions which can substantially reduce CO_2 emission.

So, some of possible technological and policy interventions which can reduce CO_2 emission, are given as below:

i. Retiring of old inefficient thermal units.
ii. Flexible operation of coal based TPPs to accommodate RES based generation.
iii. Advanced Boiler Technology such as Ultra Super-Critical (USC).
iv. Biomass Co-firing.
v. Green Ammonia Co-firing.
vi. Carbon Capture Utilization and Storage (CCUS).

It is also noted that government is already making efforts in this direction for the reduction of CO_2 in coal based TPPs by retiring old inefficient thermal units, using advanced boiler technology such as USC and cofiring of Biomass with coal. Further, NH_3 cofiring and CCUS are new promising area which can reduce the CO_2 emission substantially from coal based TPPs adding the efforts towards decarbonising the power sector.

Considering the net zero by 2050 scenario in power sector, the coal as well as gas-fired power plants may start with targets of 1% green ammonia co-firing by 2030 and 10% by 2035 aligning with IEA's Net Zero Roadmap by 2050 (2023 update)[5] and afterward target can be enhanced seeing experience, production and availability of NH_3 in the country. However, this can be far short of the "abated" target of 90% CO_2 reduction in generation phase. In addition to green ammonia co-firing, thermal power plants could install carbon capture and utilization (CCU) systems to reduce emissions.

4. Green Ammonia Co-Firing:

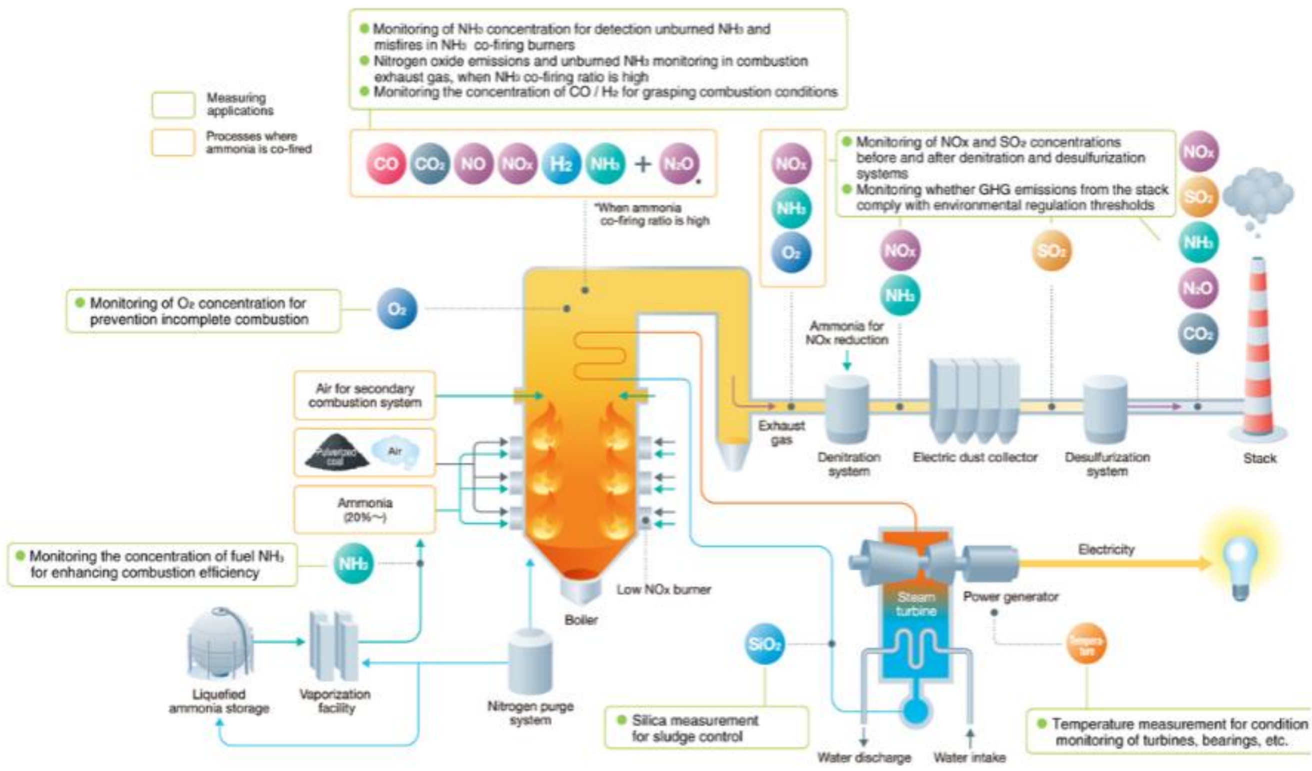
Ammonia (NH3) is a compound of nitrogen and hydrogen. It can be used as a feedstock in the chemical sector, as a fuel in direct combustion processes or in fuel cells, and as a hydrogen carrier. To be considered a low-emissions fuel, ammonia must be produced from low-emissions hydrogen.

It involves replacing some of the coal used for combustion with ammonia. By retrofitting power plants to burn ammonia, the fuel can be combusted alongside coal to generate power. The "co-firing ratio" refers to the energy content split, for example, a 20% co-firing ratio means ammonia replaces 20% of coal by energy content.

With the acceleration of efforts to utilize hydrogen and ammonia to realize a carbon-neutrality, basic research through demonstration experiments on combustion are becoming more active.

The pictorial representation for R&D / demonstration system for power generation by ammonia co-firing / 100% firing is shown as below[7]:

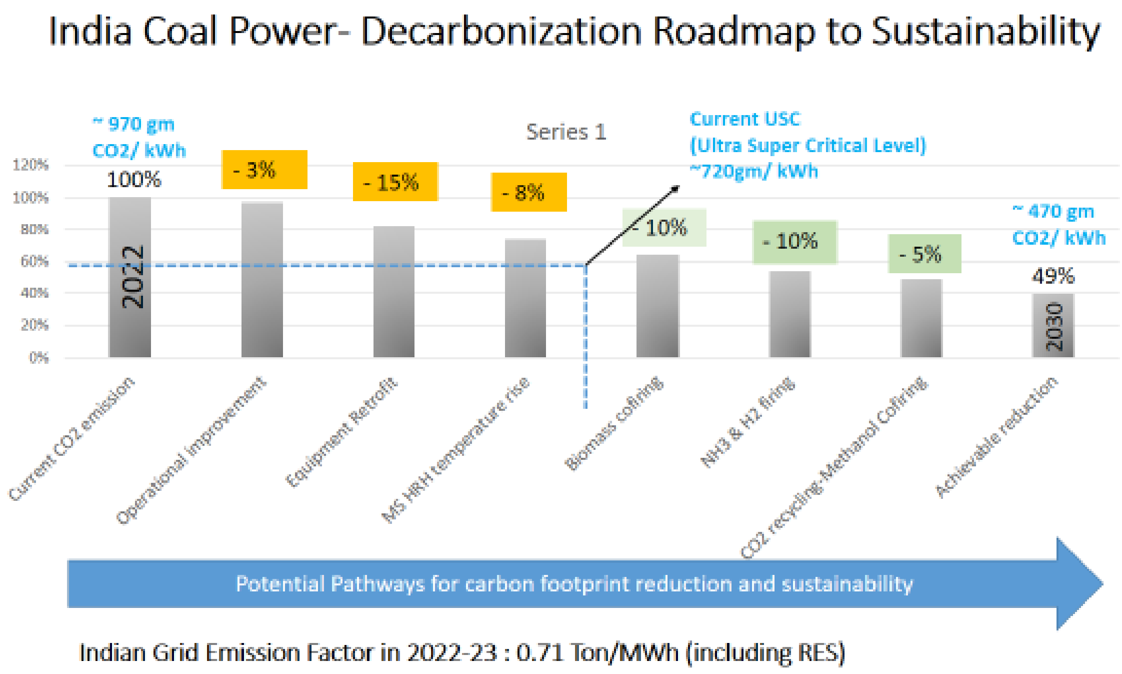
For R&D / demonstration system for power generation by ammonia co-firing / 100%



For R&D / demonstration system for power generation by ammonia co-firing / 100% firing

GE Study on potential of CO2 reduction from coal based TPPs:

The graphical representation of potential roadmap/pathway for carbon footprint reduction and sustainability as per GE study is shown as below:



Therefore, it can be said that coal based plants have the potential to remain an integral part of the grid even in NZE era, creating a win-win situation by providing the affordable solution for decarbonisation, facilitating the integration of variable renewables into the grid and utilising coal resources.

However, there are many challenges in respect to green ammonia co-firing with the pulverized coal for thermal power generation, some of the major challenges are:-

i. Modification of the Burners:- Modifying existing burners or even developing new burners for boilers is necessary to ensure a stable and efficient burning process.

ii. Lower flammability and NOx increase:- One of the significant challenges is that the combustion characteristics of ammonia differ from those of coal and natural gas. For example, the ammonia has a lower flammability in comparison with natural gas, therefore it is difficult to get stable combustion in the boiler. Therefore, firing ammonia is accompanied by the issue of reducing unburned ammonia downstream of the boiler and NOx emissions. To solve this issue, it is essential to realize stable ignition of the ammonia burner and to control the combustion area with appropriate air distribution. To achieve stable ignition, it is necessary to optimize the fuel-air mixing, air velocity, and flame stabilization structure.

iii. Ammonia Toxicity and Leak Detection: - Another challenge is the impact of toxic ammonia on living beings, which makes safety measure and leak detection critically important. Consequently, the existing infrastructure of power plants may not be sufficient and may need the implementation of leak detection system/ analysers and other safely measures.

Some of technological issues in modifying coal fired boiler are highlighted by leading technology developer i.e. Mitsubishi Heavy Industries (MHI) under Technical Review (December 2022)[8] –*"Development of Ammonia Co-firing Technology for Coal-fired Boilers toward Decarbonized Society"*, as mentioned below:

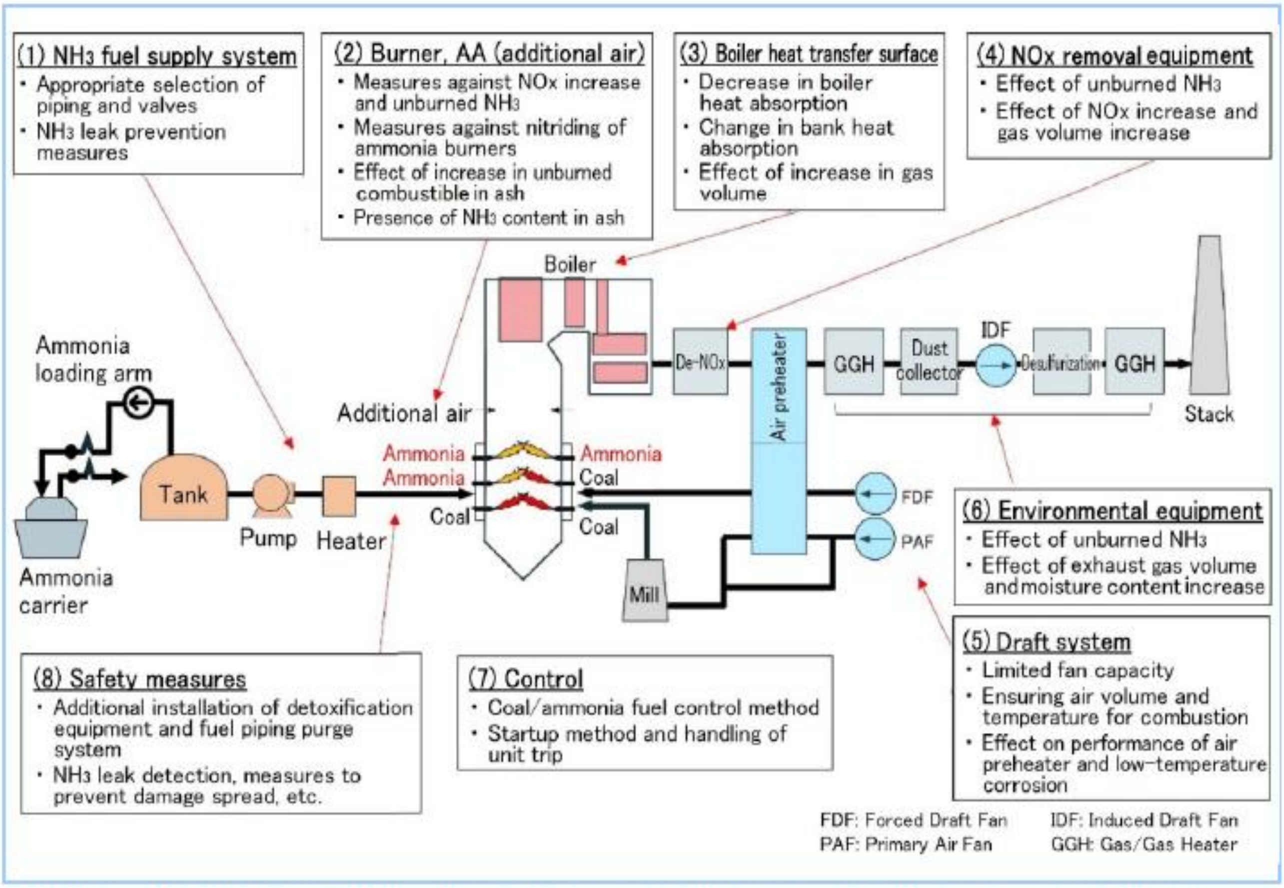


Figure 1 Technological issues in modifying coal-fired boiler to ammonia co-fired boiler

BHEL views on technological challenges:

- Ammonia (NH_3) is a green fuel and no carbon based emissions are anticipated. Ammonia (NH_3) is new fuel in Indian power plant scenario. Ammonia is gaseous fuel with lower calorific value and toxic in nature and sluggish fuel, this requires additional pilot flame for ignition. This fuel has not been tested in India but however, some studies have been conducted & reported in Japan regarding ammonia fuel co-firing with coal.
- Ammonia handling is common in fertilizer manufacturing process. BHEL is capable and already supplying Ammonia Storage and Handling system as part of SCR systems for NOx reduction in coal fired boilers.
- Trials for Ammonia Co-firing along with coal have to be conducted in the coal fired boiler to develop NH_3 firing system and to study flame stability at lower loads, ignition, flame scanner pick-up and NOx emissions etc.

5. Cost Dynamics Due to Green NH3 Cofiring:

It is noted that Ammonia can be cofired along with coal/gas after making suitable modification in existing boiler system (such as installation of additional NH3 burner, firing/combustion/flame monitoring system etc.).

The production cost of Ammonia itself depends on various factors such as H2 production cost which further relies on electrolyser cost and renewable energy cost. It is also observed that supply chain and logistic facilities for Ammonia handling are highly developed. Its production cost are expected to decline naturally as adoption increases due to both economies of scale and efficiencies gained from technological improvements.

The cost dynamics details due to green NH3 cofiring in coal as well as gas based power plants considering certain assumptions[9] is mentioned at **Annexure-1** (coal based TPPs), **Annexure-2** (Gas based TPPs). It is observed that ammonia cofiring in gas based plants seems to be more promising option than that of coal based TPPs as far as cost implication in tariff is considered. Further, green ammonia can be alternate fuel option for gas based TPPs in future.

6. Experience at global as well as country level:

Global warming is the concern of whole nations in the world. The entire world is taking collective efforts to curb the global warming. In this direction, international organization such as UNFCCC is fixing the responsibility of mitigating the climate change through COP/Paris Agreement. Considering the historical GHG emissions, the advanced economies have to phase out of unabated coal generation by 2030 to limit the 1.5C global warming.

Further, it is noted that developed nation such as Japan is making efforts and leading NH3 cofiring technology to reduce CO2 emission from coal based TPPs. Some of pilot tests[10] on NH3 cofiring in natural gas as well as coal based TPPs carried out or being carried out by some countries are enumerated as below:

Japan: In 2017, it had successfully demonstrated 1% NH3 cofiring in coal based TPP (120MW). Further, in smaller furnace with a capacity of 10MW thermal, 20% ammonia cofiring achieved without any problem.

Malaysia: 60% NH3 co-combustion trail in coal based TPP has been successfully conducted with the help of IHI and Petronas.

Singapore: Planning 100% NH3 cofiring in combined cycle gas turbine (60MW) with support of MHI and JERA.

South Korea: Planning NH3 cofiring in natural gas as well as coal based TPPs with support of SK E&S and SK Plug Hyverse.

India[11]: In Nov-2022, Adani Power Ltd (APL) has partnered with IHI and Kowa-Japan under the aegis of Japan-India Clean Energy Partnership (CEP) for conducting a pilot test on 20% NH3 cofiring in coal based TPP (330MW) at Mundra.

7. Regulatory support requirement for Green NH3 Cofiring in TPP:

In order to push the effort toward limiting the 1.5°/2°C global warming and achieving India's net zero by 2070, some of following steps may be required to achieve the cost trajectory of green NH3 production as given below:

1. Govt. budgetary support for R&D projects in field of NH3 cofiring in TPPs.

2. Promotion to more pilot projects of NH3 cofiring in coal as well as gas based TPPs.

3. Develop Policy and Regulatory framework to incentivise the early adoption of emerging technologies in area of NH3 cofiring in TPPs.

8. Seeking Views of Stakeholders on Green NH3 Cofiring:

In view of the above, this base paper is basically exploring the possibility of ammonia co-firing in new/existing coal-fired as well as gas based power plants i.e. an effort toward limiting the 1.5°/2°C global warming and achieving India's net zero by 2070.

In this regard, the valuable inputs/comments/views of power utilities, supply vendors, EPC contractors, technology providers and other stakeholders are solicited on the following lines towards decarbonizing the power sector in India context:

I. The suitability of NH3 cofiring option in natural gas as well as coal based TPPs in terms of technological feasibility, boiler performance/efficiency, flue gas characteristic, any retrofit for ammonia co-combustion, scaling(upto what % ratio of cofiring can be practical), safety aspects etc.

II. Implication on electricity tariff due to application of 1%/10%/20% NH3 cofiring in gas as well as coal based TPPs.

III. Other possible challenges in implementation of NH3 cofiring in gas as well as coal based TPPs.

Note: Please do share any technical paper/feasibility study, if any, carried out for NH3 cofiring in gas as well as coal based TPPs.

9. Reference used above with links:

S.No.	Reference
1	*https://gml.noaa.gov/ccgg/trends/global.html*
2	*https://unfccc.int/documents/636235*
3	https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf
4	https://unfccc.int/sites/default/files/resource/cma5_auv_4_gst.pdf
5	https://iea.blob.core.windows.net/assets/9a698da4-4002-4e53-8ef3-631d8971bf84/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf
6	https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_LongerReport.pdf
7	https://www.horiba.com/int/process-and-environmental/industries/alternative-fuel-combustion/
8	https://www.mhi.co.jp/technology/review/pdf/e594/e594060.pdf
9	https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf
10	https://ammoniaenergy.org/articles/ammonia-combustion-for-power-generation-updates-from-korea-malaysia-and-singapore/
11	https://www.adanipower.com/en/newsroom/media-releases/adani-power-to-co-fire-green-ammonia-at-its--mundra-plant-for-a-sustainable-future
12	https://cea.nic.in/wp-content/uploads/baseline/2024/04/User_Guide__Version_19.0.pdf

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Annexure-1

Cost Dynamics due to Green Ammonia co-firing in coal based TPPs					
S.No.	**Parameters**	**Formulae**	**Green Ammonia Co-firing**		
			2030	**2040**	**2050**
1	Green Ammonia Co-firing (%)		1%	10%	20%
2	Landed Cost# (Rs/Kg) of Green Ammonia		46	36	30
3	GCV (Kcal/Kg) of Green Ammonia$		5400	5400	5400
4	Landed Cost##(Rs/Kg) of domestic coal for non-pithead TPPs		4	4	4
5	GCV (Kcal/Kg) of domestic Coal		3600	3600	3600
6	Avg. SPCC(Kg/Kwh) of coal as per optimal gen report of CEA		0.666	0.666	0.666
7	Variable cost (Rs/kWh) due to coal only	(7)=(4)*(6)	2.66	2.66	2.66
8	Effective landed cost (Rs/kg) of coal with Ammonia cofiring	(8)=[(2)*(1)+(4)*{1-(1)}]	4.42	7.25	9.15
9	Weighted avg. SPCC(Kg/Kwh) of blended Ammonia with coal	(9)=(6)*(5)/[(3)*(1)+(5)*{1-(1)}]	0.663	0.634	0.605
10	Variable cost (Rs/kWh) due to blending of ammonia with coal	(10)=(8)*(9)	2.93	4.60	5.54
11	**Increase in variable cost (Rs/kWh)**	**(11)=(10)-(7)**	**0.27**	**1.93**	**2.88**

#Landed cost of Green Ammonia include cost of production of Green Ammonia and transportation & logistics charges, as given below: .
(a).The cost estimate for green Ammonia production (480USD/tonne in 2030, 380USD/tonne in 2040, 310 USD/tonne in 2050 at locations with the best solar & wind resources) is as per IRENA report-Renewable Ammonia (2022)[9]. [Considered 1 USD=83.45 INR as on 01.07.2024] .
(b). Assuming 15% transportation and logistics charges over the production cost for domestically manufactured green NH3. This 15% involves transportation (via truck/pipeline) charges, handling charges, conversion at port which may be higher side presently. This is indicative figure and may decline as technology adoption reaches at large scale.
$ GCV of Ammonia considered as 5400kCal/Kg based on data collected from stakeholder.
##Assuming Landed cost of domestic coal based TPPs for non-pithead location (distance from mine upto 1200 kms) may vary from 3.5-4.5 Rs/kg (considering avg 4 Rs/kg) for G13 grade coal (GCV: 3300-3600kCal/kg) (GCV of coal considered as 3600 kCal/kg).

Note:

1. Ammonia can be cofired along with coal after making suitable modification in the existing boiler system (such as installation of additional NH3 burner, milling/firing/combustion/flame monitoring system etc.). Increase in variable cost due to NH3 cofiring does not include boiler modification cost (capex/opex).
2. It is noted that wt. avg. GCV of coal consumed by coal based TPPs is observed around 3600 kCal/kg for last 4 years (FY2019-20 to FY2022-23) from CO2 baseline database report. Therefore, GCV of coal considered as 3600 kCal/kg.
3. The production cost of Ammonia itself depends on various factors such as H2 production cost which further relies on electrolyser cost and renewable energy cost. It is also observed that supply chain and logistic facilities for Ammonia handling are highly developed. Its production cost are expected to decline naturally as adoption increases due to both economies of scale and efficiencies gained from technological improvements.

Annexure-2

Cost Dynamics due to Green Ammonia co-firing in natural gas (combined cycle) based TPPs					
S.No.	**Parameters**	**Formulae**	**Green Ammonia Co-firing**		
			2030	**2040**	**2050**
1	Green Ammonia Co-firing (%)		1%	10%	20%
2	Landed Cost# (Rs/Kg) of Green Ammonia		46	36	30
3	GCV (Kcal/Kg) of Green Ammonia$		5400	5400	5400
4	Landed Cost##(Rs/Kg) of Natural Gas		61	61	61
5	GCV (Kcal/Kg) of Natural Gas$$		11579	11579	11579
6	Avg. Specific natural gas consumption(Kg/Kwh)$$		0.174	0.174	0.174
7	Variable cost (Rs/kWh) due to natural gas only	(7)=(4)*(6)	10.61	10.61	10.61
8	Effective landed cost (Rs/kg) of natural gas with Ammonia cofiring	(8)=[(2)*(1)+(4)*{1-(1)}]	60.85	58.55	54.75
9	Weighted avg. Specific consumption(Kg/Kwh) of blended Ammonia with natural gas	(9)=(6)*(5)/[(3)*(1)+(5)*{1-(1)}]	0.175	0.184	0.195
10	Variable cost (Rs/kWh) due to blending of ammonia with gas	(10)=(8)*(9)	10.64	10.75	10.66
11	**Increase in variable cost (Rs/kWh)**	**(11)=(10)-(7)**	**0.03**	**0.15**	**0.05**

#Landed cost of Green Ammonia include cost of production of Green Ammonia and transportation & logistics charges, as given below: .
(a). The cost estimate for green Ammonia production (480USD/tonne in 2030, 380USD/tonne in 2040, 310 USD/tonne in 2050 at locations with the best solar & wind resources) is as per IRENA report-Renewable Ammonia (2022)[9]. [Considered 1 USD=83.45 INR as on 01.07.2024] .
(b). Assuming 15% transportation and logistics charges over the production cost for domestically manufactured green NH3. This 15% involves transportation (via truck/pipeline) charges, handling charges, conversion at port which may be higher side presently. This is indicative figure and may decline as technology adoption reaches at large scale.
$ GCV of Ammonia considered as 5400kCal/Kg based on data collected from stakeholder.
##Landed cost of gas based TPPs is assumed as 14$/MMBTU {gas price-11$/MMBTU (based on Gas Index of India, Feb'2024), conversion & tpt cost-3$/MMBTU} [1MMBTU=25.2 SCM, 1 SCM=0.76kg].
$$Gross Heat Rate of gas (combined cycle) is considered as 2013 kcal/kWh and GCV as 8800 kCal/SCM based on CO2 baseline report (page-33 of User Guide, version-19)[12]. [Density of natural gas is assumed as 1 SCM=0.76kg]

Note:

1. Ammonia can be cofired along with gas after making suitable modification in existing boiler system (such as installation of additional NH3 burner, firing/combustion/flame monitoring system etc.). Increase in variable cost due to NH3 cofiring does not include boiler modification cost (capex/opex).
2. The production cost of Ammonia itself depends on various factors such as H2 production cost which further relies on electrolyser cost and renewable energy cost. It is also observed that supply chain and logistic facilities for Ammonia handling are highly developed. Its production cost are expected to decline naturally as adoption increases due to both economies of scale and efficiencies gained from technological improvements.