PROPOSED NEW BASELINE AND MONITORING METHODOLOGY OR METHODOLOGICAL TOOL FORM (Version 01.0)

INFORMATION TO BE COMPLETED BY THE SECRETARIAT AND METHODOLOGIES EXPERT PANEL	
Type of standard	New baseline and monitoring methodology
Unique reference number and title of the proposed new methodology or new methodological tool	A6.4-PNM001
Date when this form was received at UNFCCC secretariat:	21/04/2025
Date of posting in the UNFCCC A6.4 web site for global stakeholder consultation	23/05/2025

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[1] Format for footnotes.

SECTION A. Summary and applicability of the baseline and monitoring methodology or methodological tool

A.1. Title, submission date and version

Title: Production/Manufacture of Low Carbon Intensive Ammonia through electrolysis of water, air separation and synthesis of hydrogen and nitrogen.

Earlier Submission Date: 05th March 2025

Version: 1.0

Submission Date: 21st April 2025

Version: 1.1

A.2. If this methodology or methodological tool is based on a previous submission or an approved Article 6.4 mechanism methodology or methodological tool, please state the reference numbers here. Explain briefly the main differences and their rationale.

This methodology is **not** based on a previous submission or an approved Article 6.4 mechanism methodology.

However, it is a revised version incorporating inputs and feedback from MEP, which completed its initial assessment on April 8, 2025. (Initial_Assessment_Production_Low_Carbon_Ammonia.pdf)

A.3. Summary description of the methodology or methodological tool, including major baseline and monitoring methodological steps

This methodology is globally applicable to project activities that produce ammonia, that is less carbon-intensive than conventional ammonia production, primarily with renewable electricity for

- Production of hydrogen (H_2) using electrolysers to separate water into H_2 and O_2.
- Production of nitrogen (N) through Air Separation Plants or other facilities that use renewable energy only.
- Synthesis of hydrogen and nitrogen to produce ammonia (Haber Bosch Process).

The baseline scenario is the conservative among the following three:

(i) Best Available Technology

(ii) Ambitious benchmark and

(iii) Existing actual or historical emissions corrected for downward adjustment.

However, the baseline can be chosen from either one or two of the approaches, in cases when data and information is available for conducting these approaches. All the subprocesses to produce ammonia are to be powered mainly by renewable electricity sourced from the greenfield renewable power plant. The RE supply, use of fossil fuels, and leakages arising out of diversion of RE or water, all parameters and information that is related to baseline and project scenario are comprehensively addressed within the Monitoring framework and are thoroughly accounted for in the subsequent sections on Methodology, Recording and Verification. Life cycle emissions are considered both in baseline and activity emissions.

SECTION B. Proposed new baseline and monitoring methodology or methodological tool

B.1. Summary description and scope of the methodology or methodological tool

SECTORAL SCOPE
1. Energy Industries (renewable / non-renewable)
2. Energy Distribution
3. Energy Demand
4. Manufacturing Industries
5. Chemical Industries
6. Construction
7. Transport
8. Mining/mineral Production
9. Metal Production
10. Fugitive emissions from fuels (solid, oil and gas)
11. Fugitive emissions from production and consumption of halocarbons and sulphur hexafluoride
12. Solvent Use
13. Waste handling and disposal
14. Afforestation and reforestation
15. Agriculture
16. Carbon capture and storage of CO2 in geological formation
17. Other activities involving removals

This methodology applies to project activities that reduce greenhouse gas (GHG) emissions through the **low carbon production of ammonia** by substituting conventional, fossil-fuel-intensive processes with processes powered by **renewable electricity**. The typical projects eligible under this methodology are those that integrate:

1. **Hydrogen production** via electrolysis powered by renewable energy
2. **Nitrogen production** through air separation using renewable electricity
3. **Ammonia synthesis** through the Haber-Bosch process using the renewable energy
4. Consumption of electricity from greenfield renewable plants/supply of renewable electricity from the grid.

The methodology is applicable to:

- Greenfield ammonia plants specifically designed for low-carbon ammonia production.
- Brownfield retrofitting projects that replace fossil-based hydrogen production (e.g., via steam methane reforming of natural gas or other fossil fuels) with green hydrogen generated from renewable electricity.

Mitigation Activity:

Reduction of direct and indirect CO_2 emissions in industrial-scale hydrogen, nitrogen, and ammonia production by replacing fossil-fuel-based ammonia synthesis with processes powered by renewable energy.

Applicable Sectoral Scopes:

Scope	Sectoral Area	Justification
4	Manufacturing industries	Ammonia production as an industrial process requiring substantial energy input

B.2. Applicability conditions

The project activity involves

1. Production of green ammonia using renewable energy to power the associated processes, including the electrolyser, air separation unit, synthesis of hydrogen and nitrogen via the Haber-Bosch process, and other related utilities.
2. This methodology applies to project activities that encompass the following scenarios:

   (i) All subprocesses involved in green ammonia production are greenfield, or

   (ii) The electrolyser plant is greenfield, while other subprocesses are existing or retrofitted.
3. In the case of a brownfield or retrofitted project activity, where the electrolyser plant is greenfield and all subprocesses are existing or retrofitted, the output(s) or level(s) of service must remain identical to those in the pre-PACM project condition.
4. This methodology is limited to the production and storage of ammonia within the manufacturing facilities.
5. The electricity consumed by the ammonia production plant must be primarily sourced from greenfield renewable power plants or renewable electricity supplied via the grid, with grid electricity allowed only as a supplementary source.
6. The use of grid electricity in ammonia production and any of its subprocesses shall not exceed 10% of the total electricity consumption on an annual basis, and the designated operational entity (DOE) shall confirm compliance with this requirement.
7. The Renewable energy generation, its storage, and use may or may not be co-located.
8. Project activities may consist of modular green ammonia production equipment, in the vicinity where ammonia will be used or supplement the ammonia production in existing manufacturing facilities.
9. In cases where green ammonia production supplements an existing facility, the project must ensure clear separation and robust monitoring/metering to distinguish green ammonia from conventional output. The designated operational entity (DOE) shall confirm proper implementation by verifying the monitoring system and ensuring accurate tracking and reporting of green ammonia production.
10. The project shall limit the use of locally available water (whether surface or groundwater) for electrolysis to no more than 5%, ensuring minimal impact on water needed for drinking, agriculture, or livelihoods. Compliance with this requirement will be verified during validation and at each crediting period renewal using project data and official sources.
11. If the project activity involves installing a greenfield electrolyser within an existing ammonia production facility, the existing equipment used for hydrogen production must be decommissioned, destroyed, or properly disposed of. Failure to do so will require that emissions associated with its continued use be fully accounted for. The Designated Operational Entity (DOE) shall be responsible for verifying compliance with this requirement.

B.3. Sources and references

List the approved Article 6.4 mechanism methodological tools referenced by the methodology or methodological tool.

a) Methodology: “Feed switch in integrated Ammonia-urea manufacturing industry”. AM0050 / Version 03.0.0/ Sectoral scope: 05/EB 68

b) Methodology: Hydrogen production from electrolysis of water, AM0124 / Version 1.1 / Sectoral scope: 1,5 / EB 119A6.4-MEP005-A01 - Draft Standard: Setting the baseline in mechanism methodologies (v.03.0)

c) A6.4-MEP005-A02 - Draft Standard: Addressing leakage in mechanism methodologies (v.02.0)

d) Ammonia Production Processes from Energy and Emissions Perspectives: A Technical Brief Banafsheh Jabarivelisdeh1, Enze Jin1, Phillip Christopher2, Eric Masanet1,31 Bren school of Environmental Science and Management, University of California Santa Barbara, CA, USA 2 Department of Chemical Engineering, University of California Santa Barbara, CA, USA 3 Department of Mechanical Engineering, University of California Santa Barbara, CA, USA

e) **Product carbon footprint methodology for ammonia production by conventional steam reforming–A case study**: European Journal of Sustainable Development Research 2024, 8(1), em0241 e-ISSN: 2542-4742

f) 2006 IPCC Guidelines for National Greenhouse Gas Inventories /Section 3.2 / Chapter 3: Chemical Industry Emissions

g) Techno-Economic Challenges of Green Ammonia as an Energy Vector / Chapter 4:Ammonia Production Technologies https://doi.org/10.1016/B978-0-12-820560-0.00004-7

h) Hinico - Carbon Footprint Methodology, AEA Annual Conference, November 13 – 15

B.4. Definitions

Air Separation Plants: A plant/process that separates atmospheric air into its primary components, typically nitrogen and oxygen, and sometimes also argon and other rare inert gases. Air separation plants are constructed in different forms depending on what products are produced, production capacity, and purity

Ammonia (NH3:) Ammonia is a gas that is used a feedstock in the manufacture of fertilizers, chemicals and refrigerants.

Conventional Ammonia production: Production of NH3 that involves fossil fuels in the production of hydrogen and nitrogen separation from air

Electrolyser hydrogen production plant: A facility that produces hydrogen from the electrolysis of water. Under this methodology, the hydrogen production plant includes the desalted water station, electrolytic cell, hydrogen compressor, gas-liquid processor, hydrogen purification unit and other ancillary equipment.

Gasification of coal: an industrial process where coal is converted into syngas through a process of gasification.

Green or Low-Carbon Ammonia: Ammonia (NH3) molecules are produced by the combination of Hydrogen (H2) (produced from the electrolysis of water that uses primarily renewable energy) and Nitrogen that is separated from air).

Green Hydrogen: Production of hydrogen that consumes significantly (more than renewable electricity to power an electrolyser that separates water into hydrogen and oxygen. (Hydrogen generated through a clean and sustainable process where **renewable electricity**—such as from solar, wind, or hydro—is used to power **electrolysers** that split water (H_2O) into hydrogen (H_2) and oxygen (O_2).)

Renewable electricity: Electrical power that is generated using wind energy, solar radiation, hydro power, wave power, biomass combustion, and geothermal energy.

Steam Methane Reforming (SMR) process: In these plants, the steam reforming process for ammonia production uses natural gas to produce hydrogen, which is then combined with nitrogen to create ammonia. It is the process through which hydrogen is generated from natural gas. High-temperature steam ranging between 700°C–1,000°C is used to produce hydrogen from a methane source, such as natural gas. It is to be noted that the process is endothermic, i.e., heat must be supplied for the initiation of the reaction.

Steam reforming of natural gas: an industrial process where natural gas reacts with steam in the presence of a catalyst to produce hydrogen, carbon monoxide and releases carbon dioxide as a by-product.

Steam reforming of syngas: an industrial process where the syngas produced from the gasification of coal or oil reacts with steam in the presence of a catalyst to produce hydrogen, carbon monoxide and releases carbon dioxide as a by-product.

B.5. Baseline methodology

B.5.1. Activity boundary

The project boundary includes:

1. The specific location and grid from which renewable electricity is generated and supplied
2. The location where the hydrogen production facility consisting of electrolyser stacks; water desalination/treatment and pumping
3. The location where the Air Separation plants are located to produce nitrogen
4. The location where the hydrogen is combined/ synthesised with nitrogen to produce the green ammonia
5. The boundary of the project activity is limited to the premises of production facility(ies) and the supply sources of renewable energy

B.5.2. Baseline emissions or removals

Source	GHG[2]		Justification/Explanation
Ammonia Production, excluding transportation	CO_2	☒ Included ☐ Not included	The baseline processes are considered energy-intensive processes. Conventional ammonia production is a major emitter of CO2. In the conventional fossil fuels-based electricity generation process that is consumed to produce ammonia (even partially), CO2 will be the main GHG emitted.
	CH_4	☐ Included ☒ Not included	Methane gas emission is also considered if it is a feedstock in the production of ammonia (coal, natural gas etc)
	N_2O	☐ Included ☒ Not included	Nitrous oxides are considered insignificant and therefore not considered
	-----	☐ Included ☒ Not included	Not Applicable
Hydrogen production	CO_2	☒ Included ☐ Not included	Hydrogen is produced by use of coal or natural gas or maybe by-product of another process and therefore CO2 is the major GHG which will get emitted.
	CH_4	☒ Included ☐ Not included	Methane gas emission is also considered if it is a feedstock in the production of hydrogen
	N_2O	☐ Included ☒ Not included	Not applicable
	-----	☐ Included ☒ Not included	Not applicable
Nitrogen production	CO_2	☐ Included ☒ Not included	CO2 emitted is insignificant
	CH_4	☐ Included	Not applicable

[2] Refer to Appendix 1 of A6.4-STAN-AC-002 and A6.4-STAN-AC-004.

		☒ Not included	
	N_2O	☐ Included ☒ Not included	N_2O emitted is insignificant
	-----	☐ Included ☒ Not included	Not applicable

B.5.3. Activity emissions or removals

Source	GHG		Justification/Explanation
Low carbon intensive ammonia production, excluding transportation. Supply and/or Withdrawal of grid or fossil fuel-based electricity.	CO_2	☐ Included ☒ Not included	It is assumed that the entire ammonia production process and storage will utilise only renewable energy. Activity emissions will be considered only in case of any fossil fuel consumption or import of grid-based electricity, in the process.
	CH_4	☐ Included ☒ Not included	There are no CH4 emissions
	N_2O	☐ Included ☒ Not included	There are no N2O emissions
	-----	☐ Included ☒ Not included	No other gases are included
Hydrogen production	CO_2	☐ Included ☒ Not included	Hydrogen is produced by Electrolysis by RE use, so CO2 is not included.
	CH_4	☐ Included ☒ Not included	There is no presence of methane gas
	N_2O	☐ Included ☒ Not included	Not applicable
	-----	☐ Included ☒ Not included	No other gases are included
Low carbon intensive Nitrogen production	CO_2	☐ Included ☒ Not included	CO2 emitted is insignificant
	CH_4	☐ Included ☒ Not included	Not applicable
	N_2O	☐ Included ☒ Not included	N_2O emitted is insignificant
	-----	☐ Included ☒ Not included	Not applicable

B.5.4. ‘Business-as-usual’ (BAU) scenario

B.5.4.1. Identification of the BAU scenario

The Business-as-Usual (BAU) scenario reflects the most common ammonia production practices in the host country/region over the last three years, accounting for dominant subprocesses, energy sources, and regulatory mandates. The BAU is identified as follows:

1. Definition of BAU Subprocesses

Ammonia production under BAU is characterized by the dominant production pathway observed over the past three years. This typically includes:

1. **Hydrogen Production**

   - Steam Methane Reforming (SMR) or Coal Gasification, depending on the region's primary fossil fuel resources (e.g., natural gas or coal).
   - Electrolysis is excluded unless it accounts for >5% of national ammonia production.

2. **Nitrogen Production:**

   - Cryogenic Air Separation, the industry standard for high-purity nitrogen extraction.

3. **Ammonia Synthesis:**

   - Haber-Bosch Process, universally used to combine hydrogen and nitrogen under high pressure/temperature.
   - Direct Ammonia Production (single-step processes like electrochemical synthesis) is excluded from BAU due to lack of commercial-scale adoption in the past three years.

2. Data Collection for BAU Determination

The BAU scenario is derived from:

- Technology Prevalence: Identification of the most widely deployed technologies (e.g., SMR vs. coal gasification) based on national industry surveys, production reports, or peer-reviewed studies.
- Energy Source Dependency: Analysis of the primary feedstock (e.g., natural gas, coal, or grid electricity) used in hydrogen production, aligned with the country's resource availability.
- Regulatory Compliance: Incorporation of legally enforced efficiency standards or technology mandates (e.g., waste heat recovery requirements, emission limits) that were binding during the three-year baseline period.

3. Adjustments for Regulatory and Efficiency Mandates

The BAU scenario accounts for pre-existing regulations that influence production processes, such as:

- **Energy Efficiency Standards:** Mandated minimum efficiency levels (e.g., GJ/ton NH_3) for hydrogen production or synthesis.
- **Emission Limits:** Caps on CO_2, NOx, or SOx emissions that affect technology choices (e.g., adoption of scrubbers in coal gasification).
- **Technology Requirements:** Laws requiring specific equipment (e.g., waste heat recovery systems) in new or retrofitted plants.
- **Exclusion of Non-Compliant Practices:** Processes failing to meet regulatory requirements during the baseline period are excluded from BAU (e.g., outdated plants shut down due to non-compliance).

4. Exclusion of Emerging Technologies

The BAU scenario excludes:

- Green Hydrogen-Based Ammonia: Production pathways using renewable hydrogen (e.g., electrolysis powered by wind/solar) unless they account for >5% of national production.
- Novel Synthesis Methods: Experimental technologies (e.g., plasma catalysis, electrochemical synthesis) lacking commercial-scale adoption.

5. Conservativeness and Compliance

The BAU scenario is designed to be conservative and replicable:

- Temporal Scope: Based on the most recent three years of verifiable data to avoid speculative assumptions about future trends.
- Data Sources: Relies on auditable data (e.g., national industry reports, energy statistics, regulatory filings).
- Adjustment Safeguards: Downward adjustments are made only for **enforced regulations** (not voluntary initiatives) to prevent overestimation.

6. Methodological Steps to Determine BAU

Step 1: Collect data on ammonia production technologies, energy sources, and subprocess prevalence (last three years).

Step 2: Identify the dominant production pathway (e.g., SMR + Haber-Bosch).

Step 3: Adjust for binding regulations (e.g., efficiency standards) that alter the baseline emissions/intensity.

Step 4: Exclude emerging technologies not yet mainstream.

Step 5: Validate against national statistics and third-party industry analyses.

7. Key Output

A BAU emissions intensity (e.g., $tCO_2e/ton\ NH_3$) reflecting:

- Dominant subprocesses.
- Energy source carbon intensity.
- Regulatory-compliant efficiency levels.

B.5.4.2. Calculation of the BAU emissions or removals

BAU emission is calculated as follows:

The BAU emissions formula estimates the total greenhouse gas (GHG) emissions from ammonia production under standard conditions (before any decarbonization measures).

$$BAU_{Emission,y} = (E_{H2,y} + E_{N2,y} + E_{synthesis}) * RA \qquad \text{Equation (1)}$$

Where:

$E_{H_2,y}$: Emissions from Hydrogen production in year y

$E_{N_2,y}$: Emissions from Nitrogen production in year y

$E_{synthesis,y}$: Emissions from Ammonia Synthesis process in year y

RA : Regulated Adjustment Factor to account for policy mandated efficiency improvements

Variables:

(1) Hydrogen Production Emissions (E_{H_2})

$$E_{H2,y} = H_{req,y} * I_{H2} \qquad \text{Equation (2)}$$

Where:

$E_{H_2,y}$ **=** Emissions from hydrogen production in year y (tCO_2e)

$H_{req,y}$ = Total hydrogen produced (ton H_2)

I_{H2}= GHG intensity of hydrogen production (tCO_2e/ton H_2)

Calculation of $\mathbf{I_{H2}}$:

1. **$\mathbf{I_{H2}}$ for SMR**

   For SMR, the emissions are mainly from:

- Natural gas combustion (energy for process heating).
- Process emissions (CO_2 from methane reforming reaction).
- Electricity consumption (if any).

$$I_{H2} = E_{CH_4} + E_{combustion,SMR} + E_{electricity,SMR} \qquad \text{Equation (3)}$$

Variables:

$$E_{CH_4} = Q_{natural\ gas} * EF_{NG} \qquad \text{Equation (4)}$$

Where:

E_{CH_4} : Methane feedstock emissions

$Q_{natural\ gas}$: Quantity of natural gas consumed (tons)

EF_{CH_4} : Emission factor for natural gas used (tCO_2)

$$E_{combustion,SMR} = Q_{fuel,SMR} * EF_{fuel,SMR} \qquad \text{Equation (5)}$$

Where:

Q_{fuel} : Quantity of fuel consumed in SMR (tons)

EF_{fuel} : Emission factor for fuel used in SMR (tCO_2)

$$E_{electricity,SMR} = Q_{electricity,SMR} * EF_{grid,SMR} \qquad \text{Equation (6)}$$

Where:

$Q_{electricity}$: Quantity of electricity consumed in SMR (MWh/tH_2)

EF_{grid} : Emission factor of grid electricity used in SMR (tCO_2/MWh)

2. **$\mathbf{I_{H2}}$ for Coal gasification**

$$I_{H2} = E_{coal} + E_{combustion} + E_{electricity} \qquad \text{Equation (7)}$$

Variables:

$$E_{coal} = Q_{coal} * EF_{coal} \qquad \text{Equation (8)}$$

Where:

Q_{coal} : Quantity of coal consumed (tons)

EF_{coal} : Emission factor for coal (tCO_2)

$$E_{combustion,coal} = Q_{fuel} * EF_{fuel} \qquad \text{Equation (9)}$$

Where:

$\mathbf{E_{combustion,coal}}$: Emissions from combustion of fossil fuel in coal gasification

$\mathbf{Q_{fuel,coal}}$ **:** Quantity of fossil fuel consumed in coal gasification (tons)

$\mathbf{EF_{fuel,coal}}$ **:** Emission factor of fossil fuel used in coal gasification (tCO_2)

$$E_{electricity,coal} = Q_{electricity,coal} * EF_{grid,coal} \qquad \text{Equation (10)}$$

Where:

$\mathbf{E_{electricity,coal}}$: Emissions from electricity consumption in coal gasification (tCO_2/MWh)

$\mathbf{Q_{electricity,coal}}$ **:** Quantity of electricity consumed for coal gasification (MWh)

(2) Nitrogen Production Emissions ($\mathbf{E_{N_2}}$)

$$E_{N_2,y} = N2_{energy,y} * EF_{grid,N2} \qquad \text{Equation (11)}$$

Where:

$E_{N_2,y}$ = Emissions from nitrogen production in year y (tCO_2e/tonN2)

$N2_{energy,y}$ = Energy consumption for nitrogen production in year y (MWh/tonN_2)

$EF_{grid,N2}$= Grid emission factor (tCO_2e/MWh)

(3) Ammonia Synthesis Emissions ($\mathbf{E_{synthesis}}$)

$$E_{synthesis,y} = NH3_{energy,y} * EF_{grid,synthesis} \qquad \text{Equation (12)}$$

Where:

$E_{synthesis,y}$ = Emissions from ammonia synthesis (tCO_2e/ton NH_3)

$NH3_{energy,y}$ = Energy consumption for ammonia synthesis (MWh/ton NH_3)

EF_{grid} = Grid emission factor (tCO_2e/MWh)

Adjustments

i. Energy Mix: Replace default emission factors with country-specific values (e.g., coal-heavy grid: 0.8 tCO_2e/MWh).

ii. Regulatory Adjustments:

iii. Efficiency Gains: If regulations mandate an efficiency improvement of x%, the correction factor is:

$$RA = 1 - x\% \qquad \text{Equation (13)}$$

RA = Regulatory Adjustment Factor

x = efficiency improvement %

B.5.5. Baseline scenario

B.5.5.1. Baseline approach from paragraph 36 of the RMPs

(a) Choose one or more option(s)

☒ Best available technologies that represent an economically feasible and environmentally sound course of action, where appropriate.

☒ An ambitious benchmark approach where the baseline is set at least at the average emission level of the best performing comparable activities providing similar outputs and services in a defined scope in similar social, economic, environmental and technological circumstances.

☒ An approach based on existing actual or historical emissions, adjusted downwards to ensure alignment with paragraph 33 of the RMP.

(b) Justify the choice(s)

Option 1:

To determine the Best Available Technology (BAT) for ammonia production, that is both economically feasible and environmentally sound, a structured methodology is delineated below. This method considers the current state of technology, economic viability (including carbon pricing), and compliance with national regulations. The goal is to establish a baseline for deep decarbonization while ensuring practical implementation.

If the host country has evaluated and notified Best Available Technology for Ammonia Production, the same may be adopted.

Otherwise,

Below is a step-by-step outline for determining the BAT for ammonia production:

Step 1: Define Objectives and Scope

Objective: Identify the most economically viable and environmentally sound technology for ammonia production that aligns with deep decarbonization goals.

Scope: Focus on ammonia production via hydrogen and nitrogen synthesis.

Include technologies for hydrogen production (e.g., SMR, electrolysis) and nitrogen separation (e.g., cryogenic air separation).

Consider both existing and emerging technologies.

Incorporate compliance with national regulations and standards.

Account for carbon pricing (zero or domestic carbon price/tax).

Step 2: Establish Evaluation Criteria

Define the key criteria for evaluating technologies:

Economic Viability:

1) Capital expenditure (CAPEX) and operational expenditure (OPEX).
2) Levelized cost of ammonia (LCOA) production.
3) Sensitivity to carbon pricing (if applicable).
4) Payback period and return on investment (ROI).

Environmental Performance:

1) Greenhouse gas (GHG) emissions intensity (tonnes CO_2 per tonne NH_3).

2) Energy efficiency (GJ per tonne NH_3).
3) Resource use (water, raw materials).
4) Waste generation and byproduct management.

Regulatory Compliance:

1) Alignment with national environmental regulations (e.g., emissions limits, energy efficiency standards).
2) Compatibility with international agreements (e.g., Paris Agreement, net-zero targets).

Technical Feasibility:

1) Scalability and maturity of the technology.
2) Availability of infrastructure (e.g., natural gas pipelines, renewable energy sources).
3) Operational reliability and maintenance requirements.

Social and Strategic Factors:

1) Job creation and local economic impact.
2) Energy security and reliance on imports.
3) Public acceptance and alignment with national energy transition strategies.

Step 3: Identify Candidate Technologies

List all potential technologies for each stage of ammonia production:

Hydrogen Production

1) Steam Methane Reforming (SMR): Dominant technology; low-cost but high GHG emissions.
2) Autothermal Reforming (ATR): Improved efficiency over SMR; lower emissions.
3) Electrolysis (Green Hydrogen): Powered by renewable energy; zero emissions but higher costs.
4) Blue Hydrogen: SMR or ATR with Carbon Capture and Storage (CCS); reduced emissions.

Nitrogen Production

1) Cryogenic Air Separation: Standard technology; highly efficient but energy intensive.
2) Pressure Swing Adsorption (PSA) : Suitable for smaller-scale operations.

Ammonia Synthesis

1) Haber-Bosch Process: Dominant technology; mature and reliable.
2) Electrochemical Ammonia Synthesis: Emerging technology; low temperature and pressure but not yet commercially viable.

Step 4: Conduct Comparative Analysis

Perform a detailed comparison of candidate technologies using the evaluation criteria:

Cost Analysis:

1) Estimate CAPEX and OPEX for each technology.
2) Calculate LCOA for different candidate technologies:

Environmental Impact Assessment:

1) Quantify GHG emissions for each technology (e.g., lifecycle analysis).
2) Evaluate energy efficiency and resource use.

Regulatory Compliance Check:

Verify adherence to national emissions limits, energy efficiency standards, and other relevant regulations.

Feasibility Assessment:

1) Assess technical readiness levels (TRL) and scalability.

2) Evaluate infrastructure requirements and availability.

Step 5: Select the Best Available Technology (BAT)

Based on the comparative analysis, select the technology that meets the following criteria:

1) Economic Viability: Lowest LCOA under the given carbon pricing scenario.
2) Environmental Soundness: Lowest GHG emissions and highest energy efficiency.
3) Regulatory Compliance: Meets or exceeds national environmental and safety standards.
4) Technical Feasibility: Proven at scale and compatible with existing infrastructure.

Note: The selected Best Available Technology (BAT) shall satisfy Criteria 1, 2, 3, and 4. Of the two technologies evaluated if one meets the criteria 1, 3, and 4, and the other meets the criteria 2, 3, and 4 then the technology with the lowest GHG emissions shall be chosen.

<u>Option 2:</u>

In this option, the activity participant shall select an ambitious benchmark, where the baseline is set at least at the average emission level of the best performing comparable activities, providing similar outputs and services, in a defined scope in similar social, economic, environmental and technological circumstances.

If the host country has evaluated and notified an ambitious benchmark for Ammonia Production (in its Standardized Baseline), the same may be adopted.

Otherwise,

For baseline emissions calculations, the following steps and equations shall be applied:

Step 1: Define the Scope of Comparable Ammonia Plants

- Technology Type:
  - Include ammonia plants utilizing natural gas (SMR), coal gasification and other fossil fuel-based processes.
  - Exclude older and inefficient technologies that do not represent best practices.
- Geographical Coverage:
  - Consider global best-performing plants while ensuring alignment with regional economic and environmental conditions.
  - Use publicly available databases and industry reports to source efficiency data.
- Operational Timeframe:
  - Only plants commissioned within the last five years (to ensure relevance to Best Available Technology).
- Data Sources:
  - Industry databases (e.g., IFA, IHS Markit, Argus, UNFCCC CDM databases, corporate sustainability reports).
  - Peer-reviewed literature and verified third-party assessments.
  - If direct plant-level data is unavailable, use modelled estimates based on known best-performing technologies.

Step 2: Collect and Rank Specific Emissions Data

- Data Collection:
  - Gather specific CO_2 emissions data (SE_i, in tCO_2/tNH_3) for all identified ammonia plants that meet the scope criteria.
  - The emissions data should reflect full lifecycle emissions, including hydrogen production and ammonia synthesis.

- Rank by Efficiency:
  - Sort the ammonia plants in ascending order based on their specific CO_2 emissions (SE_i).
  - The most efficient plant has the lowest SE_i,
- Select the Top 10% Most Efficient Plants:
  - The criteria for the benchmark selection will be as follows:
  - The benchmark is set at the average emission level of the top 10% most efficient ammonia plants worldwide or in the geographical region.

Option 3:

In this option, the activity participant shall select an approach based on existing actual or historical emissions, adjusted downwards to ensure alignment with paragraph 33 of the RMP.

Step 1: Determine Historical Specific Emissions

Historical specific emissions are based on actual or past emissions data from comparable ammonia plants that have commenced operation over a defined period (typically 3–5 years)

Step 2: Apply Downward Adjustment

According to paragraph 33 of the RMP, the baseline must be adjusted downward to avoid over-crediting.

Step 3: Final Adjusted Baseline Emissions

B.5.5.2. Identification of the baseline scenario

The stepwise approach has already been explained in B.5.5.1. Based on this approach, the identification of the baseline scenario will be as follows:

$$BE_{conserv,y} = \min (BE_{BAT}, BE_{benchmark}, BE_{historical,}) \quad \text{Equation (14)}$$

The above is comparison and selection of the most conservative Baseline Emissions.

In case, the data and information is not available to reach any of the approaches, choose minimum amongst the calculated emission values using the above-mentioned approaches.

B.5.5.3. Calculation of baseline emissions or removals

Option1 –

For baseline emissions calculations, that applies **Best Available Technologies (BAT)** for ammonia production, the following equations can be applied:

$$BE_{BAT,y} = SE_{BAT,y} * P_{NH_3,y} \quad \text{Equation (15)}$$

Where:

$BE_{BAT,y}$ = Baseline CO2 emissions using BAT in year y (tCO2)

$SE_{BAT,y}$ = Specific emissions of the best available ammonia production technology in year y (tCO_2/tNH_3)

$P_{NH_3,y}$ = Quantity of Green Ammonia produced in PACM project activity in year y (tNH_3)

Option 2:

The benchmark specific emissions factor is the average emissions intensity of the top 10% most efficient ammonia plants:

- If there are N total plants, select the top 10%:

$$N_{benchmark} = [0.10 * N] \quad \text{Equation (16)}$$

- $N_{benchmark}$, **represents the best-performing ammonia production facilities**.

$$SE_{benchmark,y} = \frac{\sum_{i=1}^{N_{benchmark}} SE_i}{N_{benchmark}} \quad \text{Equation (17)}$$

Where:

$SE\_(benchmark, y)$ = Ambitious benchmark specific emissions factor (tCO2 /(tNH3)

SE_i = Specific emissions of the i-th plant in the top 10% best-performing ammonia plants (tCO_2/tNH_3)

$$BE_{benchmark,y} = SE_{benchmark,y} * P_{NH_3,y} \quad \text{Equation (18)}$$

Where:

$BE_{benchmark,y}$ = Baseline CO2 emissions using the benchmark approach in year y (tCO2)

$SE_{benchmark,y}$ = Specific emissions of best-performing ammonia production plants globally (in year y tCO_2/tNH_3)

$P_{NH_3,y}$ = Ammonia production in year y (tNH_3)

Option 3:

For baseline emissions calculations, that apply **an approach based on existing actual or historical emissions** for ammonia production, the following steps and equation shall be applied:

$$BE_{historical} = SE_{historical} * P_{NH_3,y} \quad \text{Equation (19)}$$

Where:

$BE_{historical,y}$ = Baseline CO2 emissions based on historical data in year y (tCO2)

$SE_{historical}$ = Historical Specific emissions of ammonia production (tCO_2/tNH_3)

$P_{NH_3,y}$ = Ammonia production in year y (tNH_3)

Step 1: Determine Historical Specific Emissions

$$SE_{historical,y} = \frac{\sum_{t=1}^{T} E_{CO2,y}}{\sum_{t=1}^{T} P_{NH3,y}} \quad \text{Equation (20)}$$

Where:

$SE_{historical,y}$ = Average historical emissions intensity (tCO_2/tNH_3)

$E_{CO2,y}$ = Actual CO_2 emisions from ammonia production in year y (tCO_2)

$P_{NH3,y}$ = Ammonia production in year y (tNH_3)

Step 2: Apply Downward Adjustment

A conservative factor (AF) is applied:

$$BE_{historical,y} = SE_{historical,y} - AF \quad \text{Equation (21)}$$

$$AF = \frac{SE_{historical,y}}{Y_{Net\ Zero} - Y_{SE}} \quad \text{Equation (22)}$$

Where:

AF = Adjustment Factor to align with Net Zero Target of Host Party

$SE_{historical,y}$ = Sectoral Emissions determined in year Y

$Y_{\text{Net Zero}}$ = Host Country's Net Zero Target Year

Y_{SE} = Year in which historical sectoral emissions were determined

Final Baseline Emissions with Adjustments:

$$BE_{adjusted,y} = BE_{historical,y} * P_{NH3,y} \quad \text{Equation (23)}$$

Where:

$BE_{adjusted,y}$ = Adjusted Baseline Emissions (tCO_2)

$BE_{historical,y}$ = Baseline CO2 emissions based on historical data (tCO2) in year y (tCO_2/tNH_3)

$P_{NH3,y}$ = Ammonia production in year y (tNH_3)

$$BE_{conserv,y} = \min\left(BE_{BAT,y}, BE_{benchmark}, y, BE_{adjusted,y}\right) \quad \text{Equation (24)}$$

Final Baseline Emissions

Since the most conservative emissions has been considered:

$$BE_{final,y} = BE_{conserv,y} \quad \text{Equation (25)}$$

Other key factors for Baseline Determination

- Scientific Accuracy: The methodology relies on peer-reviewed literature, industry reports, and international best practices.
- Transparency: All data sources, assumptions, and calculations are clearly documented.
- Conservativeness: Where multiple data sources exist, the most conservative (lowest) baseline emissions value is selected.
- Comparability: The selected baseline represents comparable ammonia production plants operating under similar economic and technological conditions.

Data Sources and Assumptions

- Primary Data Sources

  Whenever possible, primary data is collected from:

  - Best performing commercial ammonia plants (past 5 years)
  - Industry reports (IEA, IPCC, IRENA, Ammonia Energy Association, etc.)
  - Environmental Impact Assessments (EIA) of ammonia production facilities
  - Regulatory emissions data (EU ETS, US EPA, etc.)

Secondary Data Sources (If Primary Data is Unavailable)

Where primary data is unavailable, credible secondary sources are used, ensuring they meet the following criteria:

- Reliability: Data is obtained from authoritative sources (peer-reviewed research, government agencies, industry databases).
- Geographical & Technological Relevance: The data reflects production conditions like the project location.
- Conservativeness: The most conservative value is used if multiple datasets exist.

Example Secondary Sources:

- IPCC Emission Factors Database
- IEA Reports on Ammonia Production
- International Fertilizer Association (IFA) Production Benchmarks

B.5.5.4. Difference between BAU and baseline emissions or removals

Activity participants shall calculate the difference between the baseline emissions or removals and BAU emissions as an annual and total amount concerning the crediting period:

$$\Delta_d = BAU_{Emissions,y} - BE_{final,y} \qquad \text{Equation (26)}$$

Where:

Δ_d = Difference between BAU and baseline emissions in year y (tCO2/year)

$BAU_{Emissions,y}$ = Business As Usual Emissions in year y (tCO2e/tNH3)

$BE_{final,y}$ = Final Baseline Emissions based on the most conservative factor in year y (tCO2)

B.5.5.5. Application of downward adjustment

As this methodology requires that all three approaches be chosen and conservative amongst these as the baseline scenario, it includes host countries' ambition over time, and it is conservative and below Business as Usual (BAU). It aligns with long term temperature goal as approach 3 has a downward adjustment factor. Leakages are explicitly accounted in subsequent sections.

B.6. Activity emissions or removals

Activity emissions refer to the total direct and indirect greenhouse gas (GHG) emissions resulting from the implementation of the Green Ammonia production project. These emissions must be compared with baseline emissions to determine the net mitigation impact.

- **Activity emissions sources include:**
    - Direct onsite emissions from hydrogen and ammonia during ammonia production, including physical leaks of both gases.
    - Indirect emissions resulting from electricity consumption during the ammonia production process.
- **Data Sources and Assumptions**
    - **Primary Data Sources (Preferred)**

      Where possible, real-time operational data from the project facility is used, including:

      1. Onsite monitoring of energy consumption (electrolysers, compressors, synthesis reactors, etc.).
      2. Renewable energy supply and grid mix data (for indirect emissions calculations).
      3. Hydrogen production efficiency (electrolysis efficiency, renewable energy input, etc.).
      4. Physical leaks of hydrogen and ammonia in green ammonia production value chain.
    - **Data sources include:**
      1. Plant-level monitoring systems (SCADA, IoT sensors, flow meters, leak detection sensors etc.)
      2. Direct emissions measurements from process control systems
      3. Electricity consumption records and renewable power purchase agreements (PPAs)
    - **Secondary Data Sources (If Primary Data is Unavailable)**

If direct measurements are unavailable, secondary data is sourced from:

1. IPCC Emission Factors Database (for fuel combustion, industrial processes and GWP value).
2. International Energy Agency (IEA) reports on ammonia and hydrogen production emissions.
3. Ammonia Industry Reports (IFA, Ammonia Energy Association, etc.).

- **Regional grid hourly emission factors (from IEA, EPA, or country-specific data sources)**.
- **Ensuring Data Conservativeness:**
  - If multiple datasets exist, the most conservative (highest emissions) value shall be selected.
  - Data sources shall be selected based on geographical and technological relevance.

Steps for Calculating Activity Emissions in Green Ammonia Production

Step 1: Define System Boundary for Activity Emissions

Activity emissions are calculated for the following **key process stages**:

- **Hydrogen Production** (Electrolysis); Desalination / Treatment of water and Pumping
- **Air Separation for Nitrogen**
- **Ammonia Synthesis (Haber-Bosch Process)**

Step 2: Calculate Emissions from Electricity Use

$$E_{electricity} = C_{elec,grid,y} * EF_{elec,grid} \qquad \text{Equation (27)}$$

Where:

$E_{electricity}$ = Activity emissions from the consumption of electricity from sources other than the renewable power plant in the ammonia production project activity in year y (tCO2e).

$C_{elec,grid,y}$ = Electricity consumed in the project activity from grid in a year y ($MWh/year$)

$EF_{elec,grid}$ = Emission factor for grid electricity ($tCO2/MWh$)

Step 3: Calculate Emissions from fossil fuel Use (if any)

$$E_{fuel,y} = F_{consumed,y} * EF_{fossil-fuel} \qquad \text{Equation (28)}$$

Where:

E_{fuel} = Activity emissions from the consumption of fossil fuel in the ammonia production project activity in year y (tCO2e)$F_{consumed,y}$ = Fuel consumed by the project activity in a year y (tons/year)

EF_{fuel} = Emission factor for fuel used (tCO_2/ton of fuel)

Step 4: Calculate emissions from physical leaks of Hydrogen and Ammonia

$$E_{leaks,y} = E_{H2-leaks,y} + E_{NH3-leaks,y} \qquad \text{Equation (29)}$$

Where:

$E_{leaks,y}$ = Activity emissions due to physical leaks in ammonia production project activity in a year y

$E_{H2-leaks,y}$ = Activity emissions due to physical leaks of hydrogen in the project activity in a year y (tCO2e)

$E_{NH3\text{-}leaks,y}$ = Activity emissions due to physical leaks of ammonia in the project activity in a year y (tCO2e)

Emissions Due to Physical Leaks of Hydrogen

$$E_{H2\text{-}leaks} = H_{req,y} * PL_{H2} * GWP_{H2} \quad \text{Equation (30)}$$

Where:

$H_{req,y}$ = Mass of pure hydrogen generated by the project activity at the hydrogen production plant during year y (tH_2)

$PL_{H2,y}$ = Physical leaks of hydrogen in hydrogen value chain as a percentage of the total production in a year y (%)

GWP_{H2} = Global warming potential of hydrogen (tCO2e/tH2)

Emissions Due to Physical Leaks of Ammonia

$$E_{NH3\text{-}leaks} = P_{NH3,y} * PL_{NH3} * f_{NH3} \rightarrow NOx * GWP_{NO2} \quad \text{Equation (31)}$$

Where:

$P_{NH3,y}$ = Quantity of Green Ammonia produced in PACM project activity in year y (tNH3)

$PL_{NH3,y}$ = Physical leaks of ammonia in ammonia value chain as a percentage of the total production in a year y (%)

GWP_{NO2} = Global warming potential of nitrous oxide (tCO2e/tNH3)

$f_{NH3 \rightarrow NOx}$ = Fraction of volatilized ammonia (NH_3) that undergoes atmospheric oxidation to form nitrogen oxides (NO_x) (%)

Note: Based on the some of the research, fraction of volatilized ammonia that undergoes atmospheric oxidation to from nitrogen oxides (NOx) is very minimal (i.e.: lesser than 1%). Hence this can be neglected if country specific oxidation factor is not available.

Step 5: Calculate Total Activity Emissions

Total activity emissions are calculated as:

$$AE_y = AE_{electricity,y} + AE_{fuel,y} + AE_{leaks,y} \quad \text{Equation (32)}$$

Where:

AE_y: Activity emissions in year y (tCO2)

B.7. Leakage

B.7.1. Identifying and addressing leakages

Leakage emissions refer to the changes in anthropogenic greenhouse gas (GHG) emissions and/or removals that occur outside the defined project boundary but are attributable to the project activity. This includes emissions resulting from shifts in market demand or supply related to the project's associated outputs.

Leakage emissions sources in green ammonia production includes:

1. Transfer of Baseline Equipment
2. Competition for Resource Use
3. Diversion of Existing Production or Outputs
4. Environmental GHG Release

Data Sources and Assumptions

- **Primary Data Sources (Preferred)**

  Where possible, direct or closely linked data sources are used to assess leakage impacts, including:

  - **Tracking the fate of baseline equipment that may be transferred and used elsewhere, potentially continuing to emit GHGs.**
    - Data sources: Proof of destruction, decommission, or disposal, Equipment transfer logs, new facility emissions inventories, or usage permits.
  - **Monitoring market displacement or resource competition, especially for renewable electricity or water use, which could cause increased emissions elsewhere.**
    - Data sources: Regional grid demand/supply data, renewable energy availability reports, water usage licenses or regional hydrological data.
  - **Assessment of production displacement, where existing ammonia or hydrogen production is diverted or replaced, potentially resulting in increased emissions in alternative facilities.**
    - Data sources: Production volume tracking across facilities, market supply data, trade flow data, or industry benchmarks.
  - **Detection of unplanned or indirect GHG releases into the environment due to infrastructure or operational shifts outside the project site.**
    - Data sources: Environmental monitoring reports, remote sensing, or downstream transportation/logistics emissions data.
- **Secondary Data Sources**
    - IPCC Emission Factors Database (for fuel combustion, industrial processes and GWP value).
    - International Energy Agency (IEA) reports on ammonia and hydrogen production emissions.
    - Regional grid hourly emission factors (from IEA, EPA, or country-specific data sources).
- **Ensuring Data Conservativeness:**
    - If multiple datasets exist, the most conservative (highest emissions) value shall be selected.
    - Data sources shall be selected based on geographical and technological relevance.

B.7.2. Estimation of emission leakages

Steps for Calculating Leakage Emissions in Green Ammonia Production

Step 1: Identification of Potential Sources of Leakage

In the context of green ammonia production, potential sources of leakage include:

Step. 1.1 Transfer of Baseline Equipment (Applies to the brownfield project activities)

Leakage may occur if fossil-based ammonia production/hydrogen production equipment replaced by the project is reused elsewhere, continuing to generate GHG emissions. In accordance with paragraph 82(b) of the Standard, this methodology requires either:

- Proof of permanent decommissioning or scrapping of the baseline equipment; or

- Quantification of continued emissions if the equipment is reused.

When functional baseline equipment (e.g., steam methane reformers) is replaced but not destroyed, and continues to be used for the same purpose as in the baseline scenario, project proponents must estimate leakage emissions based on the anticipated annual operating hours, fuel consumption, output quantity, and relevant emission factors of the relocated equipment.

In cases where the baseline equipment is dismantled and its components are repurposed in a disaggregated manner across different locations and for different functions, any associated leakage emissions are not required to be considered and may be neglected, as the equipment no longer functions in its original capacity and does not contribute to continued baseline service delivery.

Step. 1.2 Competition for Resource Use

Leakage may result from increased consumption of limited resources, such as renewable electricity, water. If such competition causes other users to switch to GHG-intensive alternatives, this results in indirect emissions outside the project boundary.

The methodology includes procedures to:

- Assess the availability of critical inputs in the geographical area.
- Identify competing uses and potential displacement effects.
- Quantify associated emissions using regional or project-specific displacement factors.

Step. 1.3 Diversion of Existing Production or Outputs

If the implementation of the green ammonia project results in a change in the type or scale of production services, causing existing activities (e.g., low-emission ammonia production) to shift or be replaced by higher-emission alternatives, leakage may occur.

The methodology requires:

- Quantification of ammonia production volumes under both the conventional and project-specific methods
- An analysis of market impacts where applicable, including whether low-emission producers are displaced.
- Quantification of emissions from potential production shifts outside the project boundary.

Step. 1.4 Environmental GHG Release

Leakage may occur through indirect environmental effects triggered by the project, including:

- Land-use change associated with project activivty development (e.g., Ammonia production plant, solar farms, transmission lines)

Quantification of Leakage

Where leakage is identified as significant, it must be quantified using conservative assumptions and, where available, default emission factors or project-specific data.

The total leakage emissions (LE_{total}) for a given year shall be calculated as:

$$LE_y = LE_{equip,y} + LE_{res,y} + LE_{div,y} + LE_{env,} \qquad \text{Equation (33)}$$

Where:

LE_y = Total leakage emission in a year y (tCO_2)

$LE_{equip,y}$ = Leakage from transferred baseline equipment in a year y (tCO_2)

$LE_{res,y}$= Leakage from resource competition in a year (tCO_2)

$LE_{div,y}$ = Leakage from diversion of production in a year (tCO_2)

$LE_{env,y}$= Leakage from indirect environmental emissions in a year (tCO_2)

1. Leakage from Transferred Baseline Equipment ($LE_{equip,y}$)

This provision applies only to brownfield project activities where the baseline equipment is not disposed of or scrapped and continues to be used for the same purpose as it was prior to the pre-PACM project activity.

$$LE_{equip,y} = Q_{output,y} \times EF_{equip} \quad \text{Equation (34)}$$

Where:

$Q_{output,y}$: Output from transferred equipment (tH2/year)

EF_{equip} : Emission factor of the baseline equipment (tCO_2e/ton output)

2. Leakage from Resource Competition ($LE_{res,y}$)

In the ammonia production project activity, the primary resources involved are **renewable energy** and **water** for hydrogen production.

The **applicability conditions** of the methodology specify that:

- The project activity must source electricity **entirely from a greenfield renewable energy power plant**, with an exception allowing up to **10% electricity** to be sourced from the grid. The emissions associated with this grid usage are included in the **activity emissions**.
- The project must not consume more than **5% of the locally available water**, ensuring that there is **no significant impact** on local drinking water resources.

If a project fails to meet these applicability conditions, it is **ineligible for registration** under the Article 6.4 mechanism (PACM).

Therefore, the **risk of leakage related to resource competition** is effectively mitigated and can be **excluded from the leakage assessment** for simplification purposes.

3. Leakage from Diversion of Production ($LE_{div,y}$)

The **applicability conditions** of the methodology specify that:

The output(s) or level(s) of service delivered by the project must remain identical to those in the pre-PACM project condition.

As this requirement ensures there is no diversion of production or change in service level, calculation of leakage emissions related to such changes is not required.

Therefore, the **risk of leakage related to resource competition** is effectively mitigated and can be **excluded from the leakage assessment** for simplification purposes.

4**. Leakage from Indirect Environmental Emissions (LEenv,y)**

This provision applies to greenfield project activities. If, prior to the implementation of the PACM project, the land was used for agricultural purposes or if any land use change has occurred, the associated emissions must be accounted for.

$$LE_{env,y} = g\sum(Q_{g,y} \times GWP_g) \quad \text{Equation (35)}$$

Where:

$Q_{g,y}$: Quantity of GHG released (in tons/year)

GWP_g : Global Warming Potential of GHGs

B.8. Determination of emission reductions or net removals

$$ER_y = BE_{final,y} - AE_y - LE_y \quad \text{Equation (36)}$$

Where:

ER_y = Emission Reduction in year y (tCO_2)

B.9. Demonstration of additionality

STEP 1. Demonstration of prior consideration

The activity participants of a proposed A6.4 project shall demonstrate that the Article 6.4 mechanism benefits were considered necessary in the decision to implement the project by notifying the secretariat of the intention to seek registration of the proposed A6.4 project under the Article 6.4 mechanism through a dedicated interface on the UNFCCC website.

If the project has already started as per the definition of the "start date" of a project in the "Article 6.4 activity standard for projects", the activity participants shall submit such notification no later than 180 days after the start date of the project.

The prior consideration notification shall accompany a summary of the project information, which shall include, at minimum:

a) The project title.

b) The names of the activity participants.

c) The precise geographical location.

d) A brief description of the technologies or measures to be deployed.

e) The Article 6.4 mechanism methodology (hereinafter referred to as mechanism methodology) to be applied (if already known);

f) The actual or planned start date of the activity.

g) The type (fixed or renewable) planned start date and duration of the crediting period.

h) The approximate amount of GHG emission reductions or net GHG removals expected to be achieved by the project in each year of the crediting period.

STEP 2. Regulatory Analysis

The activity participant of the project or CP shall demonstrate that the mitigation activity is not a legal requirement. However, the activity participant shall ensure that all the rules and regulations related to the ammonia production process is mandatorily adhered to. The statutory documents (Environmental Impact Assessment, license to operate and other terms and conditions etc) shall be made available during the validation process.

The activity participant shall obtain the Host Party approval (through its DNA)

1. If the host Party approves the project, the approval shall include:
2. Confirmation that, and information on how, the project fosters sustainable development in the host Party.
3. Approval of any potential renewal of the crediting period, if the Party intends to allow the project to continue beyond the first crediting period, where the Party has specified that the crediting periods of A6.4 activities that it intends to host may be renewed pursuant to paragraph 27(b) of the RMPs;6
4. Explanation of how the project relates to the implementation of its NDC and how the expected GHG emission reductions or net GHG removals contribute to the host Party's NDC, and the purposes referred to in Article 6, paragraph 1.
5. Authorization of the activity participants

STEP 3. Avoidance of locking-in the level of emissions

Locking-in emissions refers to project activities that commit a system to a high-emission pathway (e.g., fossil fuel infrastructure with long asset lifetimes), making future decarbonization harder. Ammonia production process, based on electrolysis powered by dispatchable RE, inherently avoids lock-in. However, to rigorously demonstrate this, the following process may be applied:

1. Definition of Lock-In Emissions Criteria

Lock-in risks are identified by assessing whether the project:

1. Creates dependency on fossil fuels (e.g., requires fossil-based backup systems).
2. Extends the lifespan of high-emission infrastructure (e.g., retrofits coal plants instead of replacing them).
3. Adopts technologies with no decarbonization pathway (e.g., irreversible design choices).
4. Triggers market/regulatory shifts favouring fossil fuels (e.g., crowding out renewables).

2. Process to Identify Lock-In Emissions Risks

Step 1: Project Component Analysis

Evaluate each project component for lock-in risks:

Component	Lock-In Risk Assessment	Mitigation
Electrolysis Technology	Electrolysers are RE-powered and modular enabling upgrades	No fossil dependency; scalable design.
Dispatchable RE Source	RE (e.g., solar, wind + storage) avoids fossil backup.	Use of battery/pumped hydro ensures 24/7 RE.
Grid Interconnection	If grid-tied, ensure no reliance on fossil-dominated grids.	Off-grid design or use of 100% RE-certified grid.
Auxiliary Systems	Hydrogen storage/transport uses zero-emission methods.	Avoid methane-based compressors or pipelines.

Step 2: Comparison to Baseline (BAU)

- BAU Scenario: Fossil-based ammonia (e.g., coal/SMR plants with 30–40-year lifespans).
- Project Scenario: Electrolysis + RE systems (20–25-year lifespan, no fossil linkages).

Step 3: Qualitative Checklist

Confirm the project meets all criteria for lock-in avoidance:

- No fossil fuel combustion in any process.
- RE infrastructure is modular/upgradable (no stranded assets).
- No long-term contracts for fossil-based inputs (e.g., gas pipelines).
- Comply with national net-zero pathways (e.g., aligns with host country's 2050 targets).

3. Addressing Edge Cases:

Temporary Fossil Backup: If backup diesel generators are used during RE shortages, limit runtime to <5% annually and demonstrate a plan to phase out amid the crediting period.

OPTION 1: FINANCIAL ADDITIONALITY AND COMMON PRACTICE ANALYSISSTEP 4. Financial additionality

The activity participant shall demonstrate additionality based on the additionality standard A6.4-SBM015-A11 Demonstration of additionality in mechanism methodologies Version 1.0

Sub-step 4.1. Investment Analysis

Provide an assessment on whether the project is financially additional using an investment analysis. The analysis should in particular demonstrate that the proposed activity would not have occurred in the absence of the incentives from the mechanism through an investment analysis (default approach).

Sub-step 4.2. Barrier Analysis

The Activity participant shall demonstrate the barriers (such as first-of-its-kind, geographical, political, availability of technology, suppress demand etc) to establish additionality using this approach.

STEP 5. Common practice analysis

The activity participant shall demonstrate that such green ammonia projects are not a common practice. The appropriate tool as stipulated by Art 6.4 SB (Refer ARTICLE 6.4 Methodology Tool 24)

OPTION 2: PERFORMANCE-BASED APPROACH

STEP 4. Performance-based approach

A performance-based approach may be applied to this methodology where all of the following conditions are met:

a) This mechanism methodology uses the baseline approach(es) referred to paragraph 36 (i) or (ii) of the rules, modalities and procedures of the Article 6.4 mechanism.

b) The type of activity involves the production of a highly homogeneous product or the provision of a highly standardized service (e.g. electricity) based on the values provided on the standardized baseline for the manufacture of green ammonia.

c) The performance of the manufacture of green ammonia can be defined through one or several suitable indicators(s).

d) Information is available to demonstrate that activities with a better performance in respect to the indicator(s) have a higher likelihood of additionality.

e) Data is available or can be collected on the performance of activities with respect to the indicator(s), and the data is robust and representative.

The methodology shall also demonstrate the following, inter alia, that:

a) The baseline approach(es) applied by the project or CP are from paragraph 36 (i) or (ii) of the RMPs.

b) The technologies or practices applied in the activity outperform an ambitious threshold for emissions or emissions reductions, market penetration, or other unique characteristics, set at least at the level referred to in paragraph 36 (ii) of the RMPs.

This mechanism methodology shall require the application of one of the approaches below to setting the baseline, while considering any guidance by the Supervisory Body, and with justification for the appropriateness of the choices, including information on how the proposed baseline approach is consistent and recognizing that a host Party may determine a more ambitious level at its discretion:

A performance-based approach, considering:

a) The best available technologies that represent an economically feasible and environmentally sound course of action were appropriate.

b) An ambitious benchmark approach where the baseline is set at least at the average emission level of the best performing comparable activities providing similar outputs and services in a defined scope in similar social, economic, environmental and technological circumstances. An approach based on existing actual or historical emissions, adjusted downwards.

B.10. Methodologies principles

B.10.1. Encouraging ambition over time

a) This Mechanism methodology shall apply increasingly ambitious baselines to encourage ambition of activities over time, while considering host Party circumstances. and should facilitate the deployment of low carbon solutions and technologies as described in paragraphs 19 and 20 below.

b) Mechanism methodologies should facilitate the deployment of technologies or measures that are not widely used or available in specific locations, to facilitate knowledge transfer and encourage deployment of technologies or measures that reduce the cost of decarbonization and unlock investment in low-carbon solutions.

c) Mechanism methodologies should contain provisions that facilitate the inclusion of progressively more efficient and less greenhouse gas (GHG)-intensive technologies, replicable and scalable mitigation activities, expanding the user base, broader geographic coverage, and greater penetration of low-carbon solutions after initial deployment

In all the three approaches of baseline scenario determination, the ambition of the host party is clearly embedded, Over and above the methodology, makes provision for most conservative amongst these. The difference with BAU and locking-in emissions are quantified.

B.10.2. Contributing to the equitable sharing of mitigation benefits between participating Parties

In this methodology, the conservative amongst all the three approaches is below that of BAU and that is a contribution to the host party NDCs and beyond. Further, the lifetime of this project is 25 years which is double that of crediting period. So, the host party will share more than 70% of emission reductions beyond BAU.

B.10.3. Aligning with the NDC of each participating Party, if applicable, its LT-LEDS, if it has submitted one, the long-term temperature goal of the Paris Agreement and the long-term goals of the Paris Agreement

The activity must align with the latest NDCs and go beyond the same top contribute to LT-LEDS and Net Zero path. The activity participant is required to demonstrate the same

B.10.4. Encouraging broad participation

This methodology will be applicable in all the geographies at all scales

B.10.5. Including data sources, accounting for uncertainty and monitoring

This methodology document provides data sources, accounting for uncertainty and monitoring

B.10.6. Taking into account policies and measures and relevant circumstances

The methodology contains provisions to consider relevant circumstances, including national, regional, or local, social, economic, environmental and technological, based on robust data and verifiable information. The type of data and information that would be necessary to demonstrate eligibility conditions, set the baseline, and demonstrate additionality is specified in the methodology.

B.11. Reversals

Not applicable, as the methodology does not cover removal-type project activities.

B.12. Monitoring methodology

B.12.1. Data and parameters not monitored

Data/parameter	I_{H2}
Description	*GHG intensity of hydrogen production in BAU scenario*
Data unit	*tCO2eq/ton of hydrogen produced*
Equations referred	*Equation 2*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*If the parameter is from 'Other sources', indicate the source of the parameter and justify the choice of the data.*
Additional comments	*No comments*

Data/parameter	$Q_{natural\,gas}$
Description	*Quantity of natural gas consumed in the SMR Process in BAU scenario*
Data unit	*Tonnes/tH_2*
Equations referred	*Equation 4*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	EF_{NG}
Description	*Emission factor for natural gas consumed in the SMR Process in BAU scenario*
Data unit	*tCO_2/tNG*
Equations referred	*Equation 4*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	***2.75***

Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	IPCC (2006) – Guidelines for National Greenhouse Gas Inventories, Volume 2
Additional comments	*No comments*

Data/parameter	$Q_{fuel,SMR}$
Description	*Quantity of fuel consumed in SMR process in BAU scenario*
Data unit	*GJ/tH2*
Equations referred	*Equation 5*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	$EF_{fuel,SMR}$
Description	*Emission factor for fuel consumed in SMR in BAU scenario*
Data unit	*a. If* $\mathbf{Q_{fuel,SMR}}$ *is in* $\mathbf{GJ}$*, then take unit as* $\mathbf{tCO_2e/GJ}$*.* *b. If* $\mathbf{Q_{fuel,SMR}}$ *is in* $\mathbf{m^3}$*, then take unit as in* $\mathbf{tCO_2e/m^3}$*.*
Equations referred	*Equation 5*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	**0.0561 tCO_2e per GJ**
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	IPCC (2006) – Guidelines for National Greenhouse Gas Inventories, Volume 2
Additional comments	*No comments*

Data/parameter	$Q_{electricity,SMR}$
Description	*Quantity of electricity consumed in SMR*
Data unit	*MWh/tH2*

Equations referred	*Equation 6*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc. (CEA Data)*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	Q_{coal}
Description	*Quantity of coal consumed in gasification process*
Data unit	*Tons/tH2*
Equations referred	*Equation 8*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	EF_{coal}
Description	*Emission factor for coal consumed in coal gasification in BAU scenario*
Data unit	*tCO_2e/tonnes*
Equations referred	*Equation 8*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	***1.81***
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*2006 IPCC Guidelines for National Inventories*

Additional comments	*No comments*

Data/parameter	Q_{fuel}
Description	*Quantity of fossil fuel consumed in coal gasification in BAU scenario*
Data unit	*Tons/tH₂*
Equations referred	*Equation 9*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	EF_{fuel}
Description	*Emission factor for fuel used in coal gasification in BAU scenario*
Data unit	$tCO_2e/tonnes$
Equations referred	*Equation 9*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*2006 IPCC Guidelines for National Inventories*
Additional comments	*No comments*

Data/parameter	$Q_{electricity,coal}$
Description	*Quantity of electricity consumed for coal gasification in BAU scenario*
Data unit	MWh/tH_2
Equations referred	*Equation 10*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	-

Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	$EF_{grid,coal}$
Description	*Emission factor for grid electricity consumed in coal gasification in BAU scenario*
Data unit	*tCO_2e/MWh*
Equations referred	*Equation 10*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	-
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Combined Margin CO2 emission factor in year y*
Additional comments	*No comments*

Data/parameter	$EF_{grid,SMR}$, $EF_{grid,N2}$ and $EF_{grid,synthesis}$
Description	*Emission factor of the electricity source supplying electricity to the Nitrogen production and synthesis of nitrogen and hydrogen plant in BAU scenario*
Data unit	*tCO_2e/MWh*
Equations referred	*Equation 6, Equation 11 and Equation 12*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	-
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Combined Margin CO2 emission factor in year y*
Additional comments	*No comments*

Data/parameter	$N2_{energy,y}$
Description	*Energy consumption for nitrogen production in year y in BAU scenario*

Data unit	*MWh/tN2*
Equations referred	*Equation 11*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	-
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	$NH3_{energy,y}$
Description	*Energy consumption for ammonia synthesis in BAU scenario*
Data unit	*MWh/tNH3*
Equations referred	*Equation 12*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	-
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	$SE_{BAT,y}$
Description	*Specific emissions of the best available ammonia production technology* (tCO_2/tNH_3) *in year y*
Data unit	$tCO_2e/\ tNH_3$
Equations referred	*Equation 15*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	-
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*

Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	$SE_{benchmark,y}$
Description	*Specific emissions of best-performing ammonia production plants globally* (tCO_2/tNH_3) *in year y*
Data unit	$tCO_2/\ tNH_3$
Equations referred	*Equation 17*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	-
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	$SE_{historical,y}$
Description	*Historical Specific emissions of ammonia production* (tCO_2/tNH_3)
Data unit	$tCO_2/\ tNH_3$
Equations referred	*Equation 20*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	-
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc.*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	EF_{fuel}
Description	*CO2 emission factor of the fossil fuel*
Data unit	*tCO_2/ton of fuel*
Equations referred	*Equation 28*

Purpose of data	☐ Baseline emissions / removals ☒ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	-
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data,* ***IPCC****, commercial and scientific literature, etc*
Choice of data or measurement methods and procedures	*2006 IPCC Guidelines for National Inventories*
Additional comments	*No comments*

Data/parameter	*GWP_{H2}*
Description	*Global warming potential of Hydrogen*
Data unit	*$tCO_2/tonH_2$*
Equations referred	*Equation 30*
Purpose of data	☐ Baseline emissions / removals ☒ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	*5.8*
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data,* ***IPCC****, commercial and scientific literature, etc*
Choice of data or measurement methods and procedures	*IPCC AR4 WG1 as under chapter 2.10.3.6*
Additional comments	*The GWP value is calculated as an indirect 100-year GWP*

Data/parameter	*GWP_{NO2}*
Description	*Global warming potential of Nitrous Oxide*
Data unit	*$tCO_2/tonNH_3$*
Equations referred	*Equation 31*
Purpose of data	☐ Baseline emissions / removals ☒ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	***273***
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data,* ***IPCC****, commercial and scientific literature, etc*
Choice of data or measurement methods and procedures	*IPCC Sixth Assessment Report, 2020 (AR6)*
Additional comments	*The GWP value is calculated as an indirect 100-year GWP*

Data/parameter	$f_{NH3 \rightarrow NOx}$
Description	*Fraction of volatilized ammonia (NH_3) that undergoes atmospheric oxidation to form nitrogen oxides (NO_x) (%)*
Data unit	*%*
Equations referred	*Equation 31*
Purpose of data	☐ Baseline emissions / removals ☒ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	***1%***
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks/country specific oxidation factor if available any to ensure accuracy and represent best available technology standards.*
Additional comments	*No comments*

Data/parameter	EF_{equip}
Description	*Emission factor of the baseline equipment (tCO_2e/ton output)*
Data unit	*%*
Equations referred	*Equation 34*
Purpose of data	☐ Baseline emissions / removals ☒ Project emissions / removals ☒ Leakage emissions *Tick the applicable box(es).*
Value(s) applied	*-*
Source of data	☐ Measured ☒ Other sources *Tick the applicable box. 'Other sources' include official statistics, expert judgment, proprietary data, **IPCC**, commercial and scientific literature, etc*
Choice of data or measurement methods and procedures	*Data sourced from recognized literature and benchmarks to ensure accuracy and represent best available technology standards.*
Additional comments	*This pertains to the brownfield project activity, where the baseline equipment is neither discarded nor disposed of, but continues to be used after its transfer to the other party. The emission factor is determined by the method of ammonia production and is multiplied by the quantity of output*

B.12.2. Data and parameters monitored

BAT scenario over the entire crediting period

Data/parameter	*BAT: Best Available Technology*
Description	*Description of the process and attributable emissions to the technology*
Data unit	*tCO2/unit production of each feedstock (Hydrogen/Nitrogen/Ammonia/Any byproducts*
Equations referred	

Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*	
Measurement methods and procedures	*Endorsed/reviewed peer studies by credible entities and available in public domain* *Updated provided by respective Governments/Industry Associations/Reputed Manufacturing Organisations.* *The studies should demonstrate how key factors such as Financial/Economic viability, Scalability, Existing manufacturing facilities of comparable scale, Environmental and Sustainability (meet SDGs) and Regulatory compliances have been assessed.*	
Measuring instrument(s)	*Type of instrument*	May be part of the peer reviewed studies/pilot projects/
	Location	Pilot Studies
Monitoring intervals	*Annual basis*	
Additional comment	No comments	

Performance Based Approach over the entire crediting period

Data/parameter	$Performance\ Based\ Approach$
Description	*Information available to demonstrate that activities with a better performance in respect to the indicator(s) have a higher likelihood of additionality.* *Data is available or can be collected on the performance of activities with respect to the performance indicator (s as explained in the PDD and the data is robust and representative.*
Data unit	*The indicator(s) shall be a good proxy for the likelihood for additionality by demonstrating better performance in respect to the indicator(s).* *Indicator(s) may be based on different metrics such as greenhouse gas emissions intensity, market penetration or other unique characteristics of the type of activity. geographical areas to which the methodology is applicable. Where possible, the correlation between the indicator(s) and the likelihood of additionality should be quantified.*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Monitoring intervals	*Annual basis*
Additional comment	Any comment may be provided if necessary

Downward Adjustment Factor

Data/parameter	*AF*
Description	*A "downward adjustment factor" is applied to the baseline over time, gradually reducing the allowed emission level, ensuring that the project must achieve progressively greater emission reductions to generate carbon credits.*
Data unit	*Fraction or percentage* *Downward adjustments are made only for **enforced regulations** (not voluntary initiatives) to prevent overestimation.*

Equations referred	*Equation 22*
Purpose of data	☒ Baseline emissions / removals ☐ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Measurement methods and procedures	Alignment with NDC/LT- LED Downward adjustments are made only for enforced regulations (not voluntary initiatives) to prevent overestimation.
Additional comment	Comments may be provided if necessary

Data/parameter	$F_{consumed}$	
Description	*Fuel consumed by the project activity*	
Data unit	*Tons*	
Equations referred	*Equation 28*	
Purpose of data	☐ Baseline emissions / removals ☒ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*	
Measurement methods and procedures	*Based on Inventory balance, purchase orders of the fuel.*	
Entity/person responsible for the measurement	Plant operation	
Measuring instrument(s)	*Type of instrument*	*Levelling scale or flowmeters(transducers).*
	Accuracy class	Not applicable.
	Calibration requirements	Based on national standards.
	Location	*In the fuel storage yard.*
Measurement intervals	*Continuous*	
QA/QC procedures	*As specified in the Standard Operating Procedures (SOP)*	
Additional comment	Comments may be provided if necessary	

Data/parameter	$P_{NH_3,y}$
Description	*Quantity of Green Ammonia produced in PACM project activity in year y*
Data unit	*tNH_3*
Equations referred	Equation 15, Equation 18, Equation 19, Equation 23, Equation 31
Purpose of data	☒ Baseline emissions / removals ☒ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*
Measurement methods and procedures	Flowmeter or load cell
Entity/person responsible for the measurement	Plant operation

Measuring instrument(s)	*Type of instrument*	Level controller (Electronic/Scale) connected to SAP
	Accuracy class	Class 0.5, Class 1, or Class 1.5
	Calibration requirements	*As per national standards.*
	Location	Anhydrous Ammonia transfer area to the storage tanks.
Measurement intervals	*Continuous*	
QA/QC procedures	*As specified in the Standard Operating Procedures (SOP)*	
Additional comment	No comments	

Data/parameter	$H_{req,y}$	
Description	*Total hydrogen production*	
Data unit	***tons** (weight) or volume cubic metre(m3) units*	
Equations referred	Equation 2, equation 30	
Purpose of data	☒ Baseline emissions / removals ☒ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*	
Measurement methods and procedures	*Digital Flowmeters (in case measured in volume) or Load cells (in case measured by weight)* *Note: In case the flow is measured on volume basis, then it has to be converted to weight basis. (Mass = Volume * Density)*	
Entity/person responsible for the measurement	Plant operations	
Measuring instrument(s)	*Type of instrument*	Digital Electronic Flowmeter interfaced with SAP or Load Cells
	Accuracy class	Class 0.5, Class 1, or Class 1.5
	Calibration requirements	*As per national standards.*
	Location	Hydrogen transfer area
Measurement intervals	*Continuous*	
QA/QC procedures	*As specified in the Standard Operating Procedures (SOP)*	
Additional comment	No comments	

Data/parameter	PL_{NH3}
Description	*Physical leaks of ammonia in ammonia value chain as a percentage of the total production*
Data unit	***%***
Equations referred	*Equation 31*

Purpose of data	☐ Baseline emissions / removals ☒ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*	
Measurement methods and procedures	*Leak Detection sensors*	
Entity/person responsible for the measurement	Plant operations	
Measuring instrument(s)	*Type of instrument*	Gas leak detection sensors (e.g., ammonia detectors) integrated with SAP or SCADA systems for real-time monitoring and alerts
	Accuracy class	Sensor-specific; typically, qualitative or ppm-level accuracy
	Calibration requirements	*As per manufacturer guidelines and national safety standards*
	Location	Ammonia production and storage areas
Measurement intervals	*Continuous*	
QA/QC procedures	*As specified in the Standard Operating Procedures (SOP)*	
Additional comment	No comments	

Data/parameter	PL_{H2}	
Description	*Physical leaks of Hydrogen in hydrogen value chain as a percentage of the total production*	
Data unit	*%*	
Equations referred	*Equation 30*	
Purpose of data	☐ Baseline emissions / removals ☒ Project emissions / removals ☐ Leakage emissions *Tick the applicable box(es).*	
Measurement methods and procedures	*Leak Detection sensors*	
Entity/person responsible for the measurement	Plant operations	
Measuring instrument(s)	*Type of instrument*	Gas leak detection sensors integrated with SAP or SCADA systems for real-time monitoring and alerts
	Accuracy class	Sensor-specific; typically, qualitative or ppm-level accuracy
	Calibration requirements	*As per manufacturer guidelines and national safety standards*
	Location	Hydrogen production and storage areas
Measurement intervals	*Continuous*	
QA/QC procedures	*As specified in the Standard Operating Procedures (SOP)*	
Additional comment	No comments	

Data/parameter	$Q_{g,y}$	
Description	*Quantity of GHGs released*	
Data unit	*tGHGs*	
Equations referred	Equation 35	
Purpose of data	☐ Baseline emissions / removals ☐ Project emissions / removals ☒ Leakage emissions *Tick the applicable box(es).*	
Measurement methods and procedures	Life-cycle assessment (LCA)-based estimation.	
Entity/person responsible for the measurement	-	
Measuring instrument(s)	*Type of instrument*	NA
	Accuracy class	-
	Calibration requirements	*As per national standards.*
	Location	Ammonia production plant
Measurement intervals	*Onetime*	
QA/QC procedures	*As specified in the Standard Operating Procedures (SOP)*	
Additional comment	*Applicable only if the greenfield project activity affects land use, agricultural practices, etc.*	

B.12.3. Monitoring for activities involving removals and emission reduction activities with reversal risks

Not applicable, as the methodology does not cover removal-type project activities.

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Document information

Version	*Date*	*Description*
01.0	18 December 2024	Initial publication of form template.

Decision Class: Regulatory
Document Type: Form
Business Function: Methodology
Keywords: A6.4 mechanism, developing methodologies and tools

Note: The below Annexure is for reference purpose only and shall be removed after the review by the MEP

Annexure (Process description and flowcharts)

Conventional Ammonia Production Process

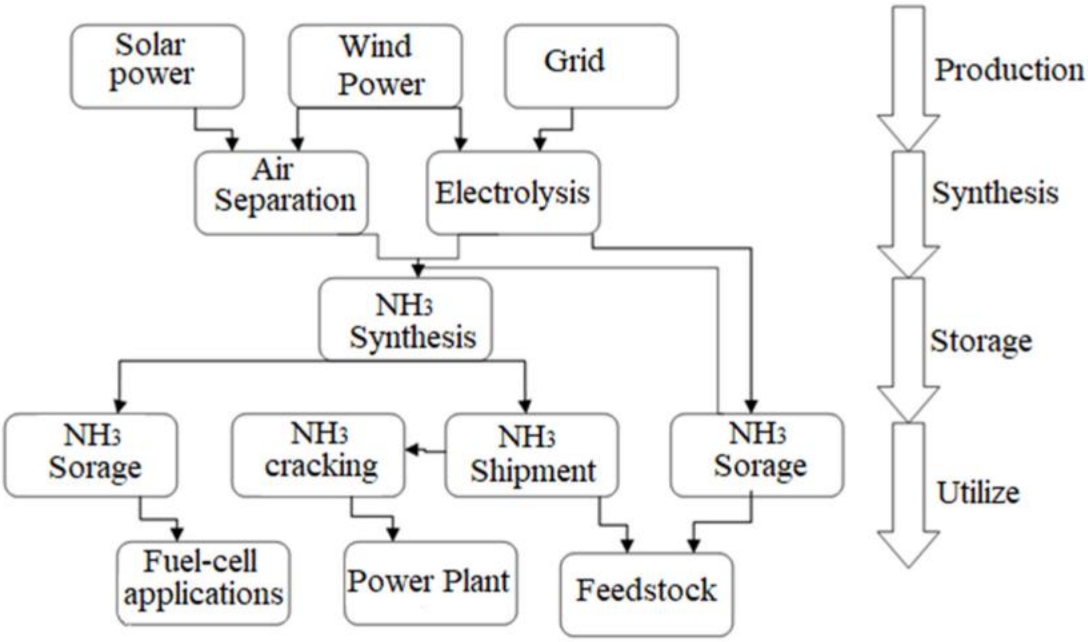


Figure 6. Schematics of the green ammonia process from production to utilization, reproduced from

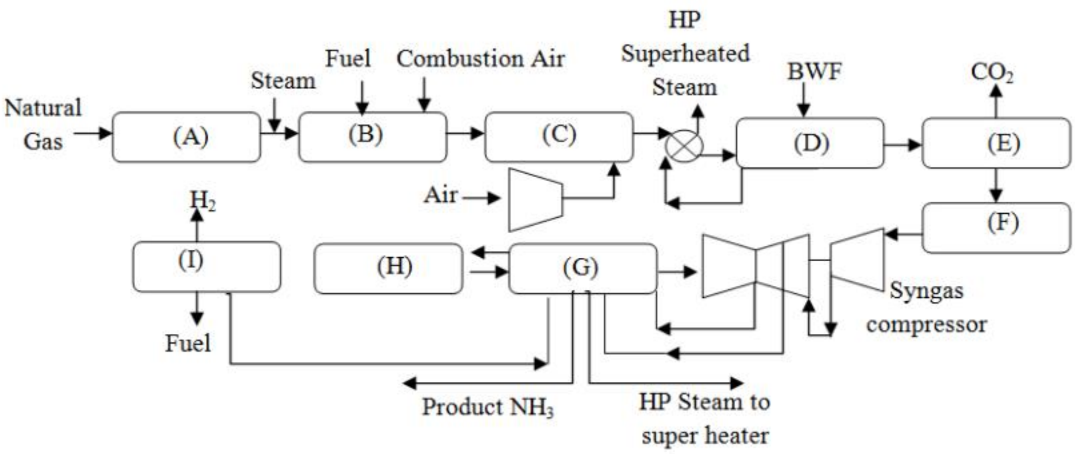


Figure 2. Block diagram of conventional NH_3 production, reproduced from the reference [8]. (A) Desulfurization (B) Primary Reformer (C) Secondary Reformer (D) CO shift (E) CO_2 removal (F) Methanation (G) NH_3 loop (H) Refrigeration (I) NH_3 Loop.

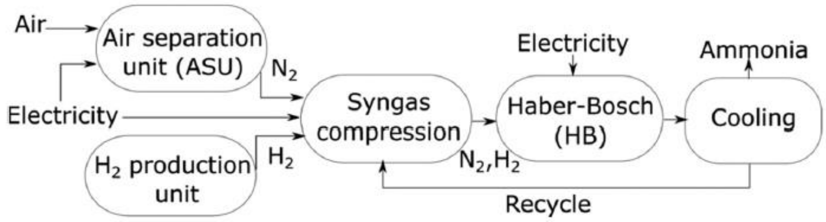
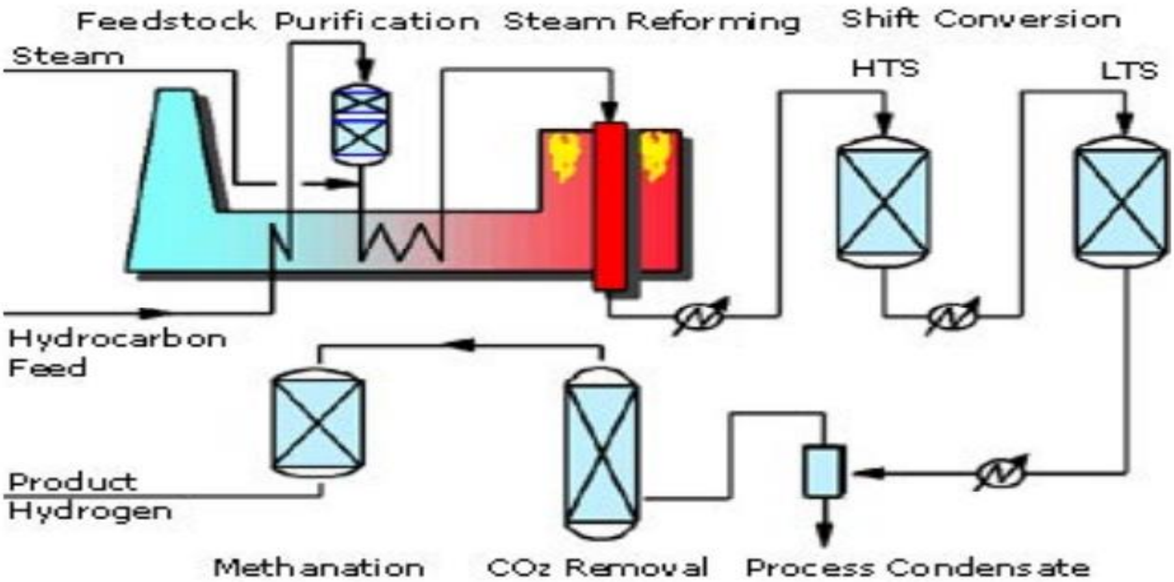
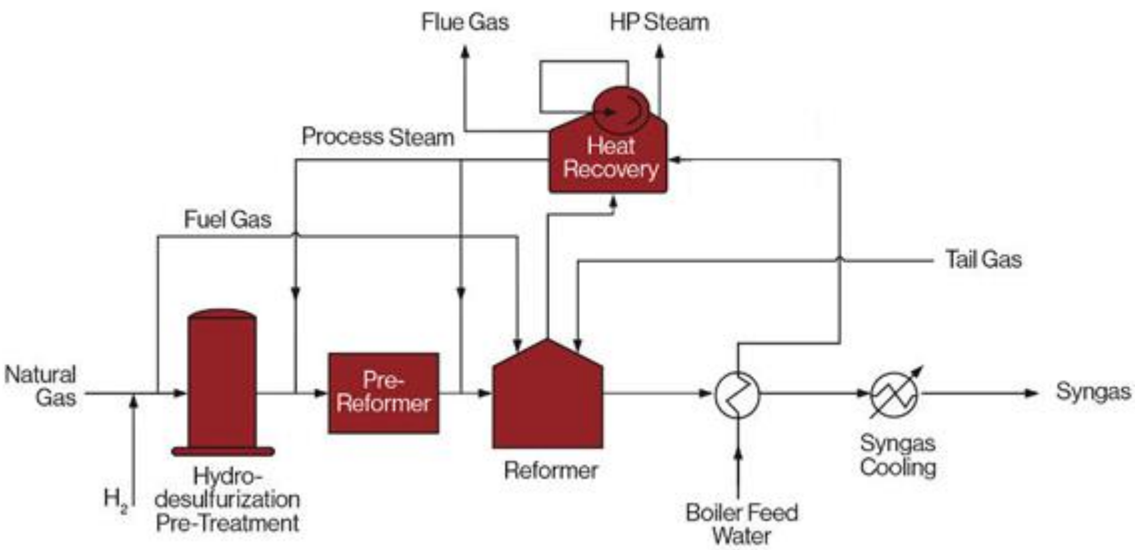


Fig. 2 Process diagram for alternative ammonia production pathways.

Conventional Hydrogen Production Process

Figure 1: Steam Methane Reforming Process





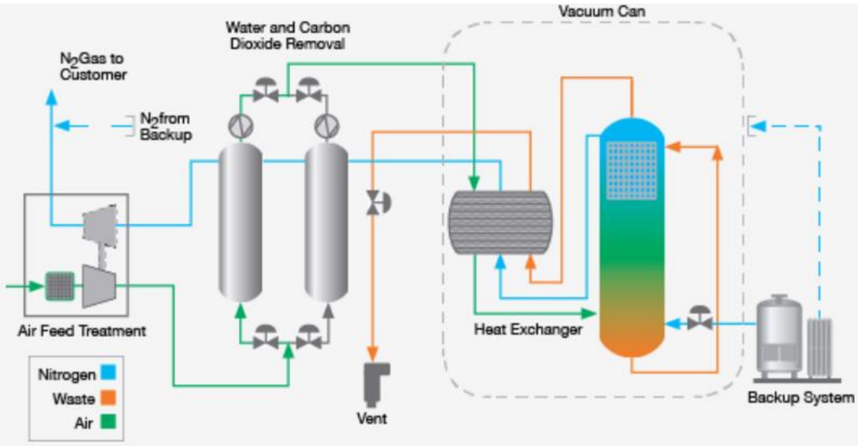
The CO_2 emissions per kg of hydrogen produced can vary greatly depending on the method of production used.

- *Steam Methane Reforming (SMR) is the most common method of hydrogen production, and it typically results in CO_2 emissions of around 8-10 kg CO_2 per kg of hydrogen produced. This is because the process involves reacting methane (natural gas) with steam to produce hydrogen and CO_2. The emissions from this process are directly proportional to the carbon content of the natural gas used.*
- *Coal Gasification is another method of hydrogen production, it typically results in CO_2 emissions of around 14-15 kg CO_2 per kg of hydrogen produced. This is because the process involves reacting coal with steam to produce hydrogen and CO_2. This method is highly polluting and energy intensive.*
- *Steam reforming of natural gas offers an efficient, economical, and widely used process for hydrogen production, and provides near- and mid-term energy security and environmental benefits. The efficiency of the steam reforming process is about 65% to 75%, among the highest of current commercially available production methods. Natural gas is a convenient, easy to handle, hydrogen feedstock with a high hydrogen-to-carbon ratio. It is also widely available from sources in most of the countries across the world.*
- *During the production of hydrogen, CO_2 is also produced. The SMR process in centralized plants emits more than twice the CO_2 than hydrogen produced.*
- *Carbon Captue: To avoid emission of CO_2 into the atmosphere, CO_2 can be concentrated, captured, and sequestered; sequestration concepts and technologies are relatively new and there is no long-term test evidence to prove that these technologies will be successful. Sequestration in oceans is controversial because of the possible adverse impact on the aquatic environment by the reduction of ocean water pH.*
- *Biomass Gasification is a method of hydrogen production that typically results in CO_2 emissions of around 2-3 kg CO_2 per kg of hydrogen produced. This is because the process involves reacting biomass (such as wood, agricultural waste, or sewage) with steam to produce hydrogen and CO_2. The emissions from this process are considered to be low, as the CO_2 produced is considered to be "carbon neutral" since it comes from a renewable source.*
- *Electrolysis of water is a method of hydrogen production that typically results in CO_2 emissions of around 1-2 kg CO_2 per kg of hydrogen produced. The emissions from this process are directly proportional to the carbon content of the electricity used.*
- *Photolysis is a method of hydrogen production that typically results in CO_2 emissions of around 0 kg CO_2 per kg of hydrogen produced. This is because the process involves using solar energy to split water into hydrogen and oxygen and does not produce any CO_2 emissions.*
- *Overall, the “cleanest” hydrogen production methods in terms of CO_2 emissions per kg of hydrogen are electrolysis of water using renewable energy or photolysis.*
- *The shift to a low-carbon, hydrogen-based economy is prompting the energy industry to explore more cost-effective and sustainable technologies, including methane pyrolysis (turquoise hydrogen), which offers significantly lower carbon emissions than steam methane reforming (SMR) and provides a more economical alternative to existing electrolysis-based green hydrogen production.*
- *Methane pyrolysis's cost-effectiveness can be further enhanced through the effective utilization of the solid carbon byproduct, which none of the other competing technologies produce.*
- *The solid carbon produced has potential applications across diverse sectors, such as electronics, energy storage systems, tire production, agricultural additives, and construction materials. Currently, emerging companies are at the forefront of methane pyrolysis research, development, and commercialization. Research encompasses thermal, thermocatalytic, and plasma decomposition methods for methane cracking, with each method offering unique advantages.*
- *This study opens by offering a comparative analysis of methane pyrolysis with conventional hydrogen production technologies (SMR and water electrolysis). It covers multiple aspects of hydrogen production through methane pyrolysis, providing an overview of the thermal, thermocatalytic, and plasma pyrolysis processes.*

  The study evaluates each method's strengths and challenges and highlights the pioneering companies in each segment. In addition, it offers insight into the technology's driving forces and challenges and provides a techno-economic analysis of the various processes associated with methane pyrolysis. It also covers the patent landscape and offers a comprehensive analysis of the growth opportunities projected to play a pivotal role in driving the adoption of methane pyrolysis technology.

Conventional Nitrogen Production Process

The PSA process: The steps in the PSA process of nitrogen generation involve passing compressed air through a tower containing an adsorbent material such as a carbon molecular sieve that adsorbs oxygen in preference to nitrogen. The oxygen in the compressed air is removed by the adsorbent material, leaving behind nitrogen. When the adsorbent material is saturated, the oxygen in it is desorbed. In practice, two towers with adsorbent material are used alternately so that the production of nitrogen is continuous: Step 1 Nitrogen production using a pressure swing adsorption process



▲**Figure 2.** In a cryogenic air separation system, the feed is compressed and cooled to remove water vapor, carbon dioxide, and hydrocarbons before it enters the vacuum can, where a...

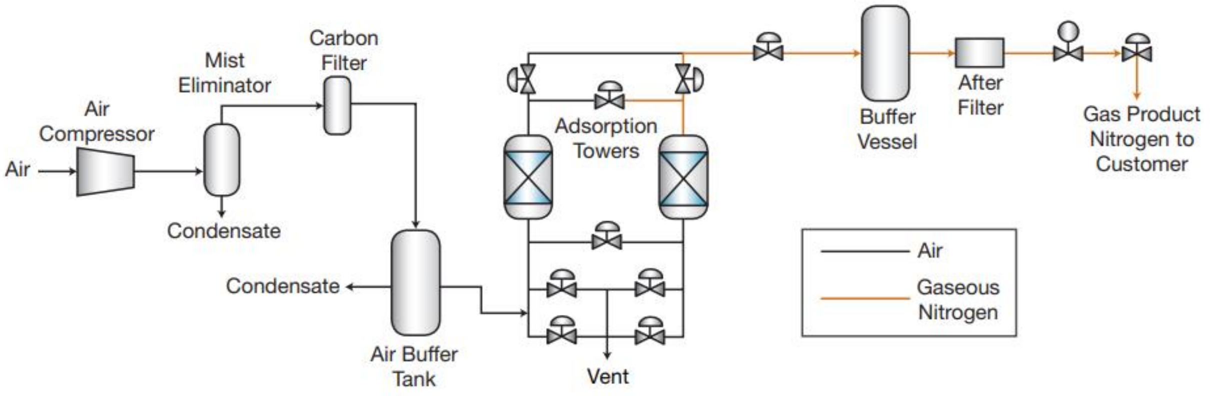


Figure 1. PSA systems can provide a reliable, low-cost nitrogen supply to meet a wide variety of process requirements.

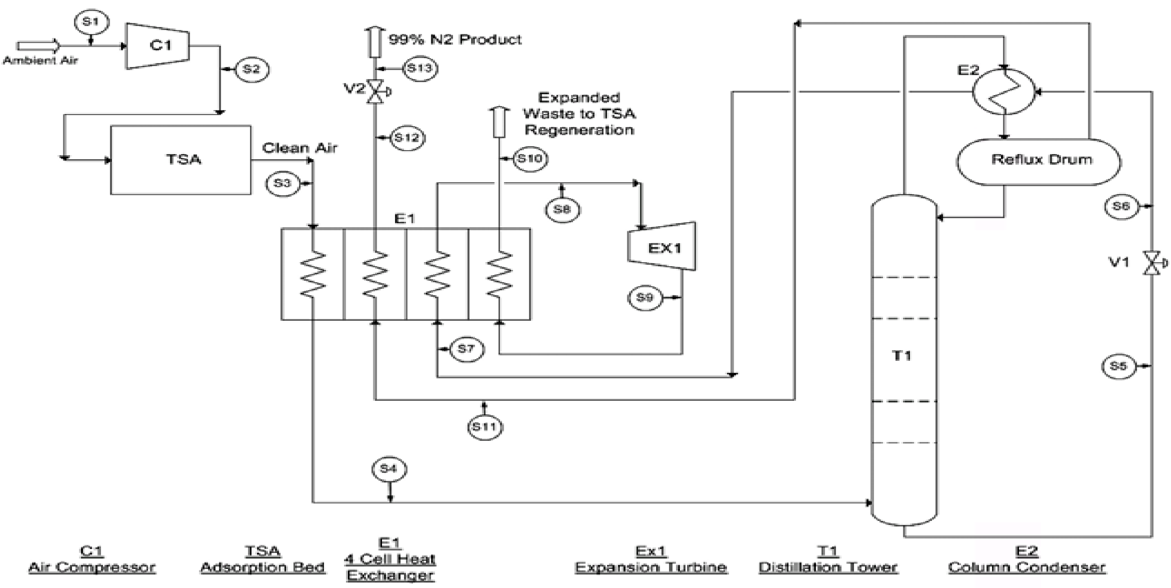


Figure 3: Simplified flow diagram of cryogenic process

Air separation plants extract gases from the air by distillation, primarily producing oxygen and nitrogen. Some facilities also recover argon, carbon dioxide, helium, neon, krypton, and xenon. These plants can be designed to produce either liquid or gaseous products and customized to extract specific gases while discarding others.

Emissions from ASUs

Air separation plants generate minimal emissions, mainly consisting of air gases and impurities returned to the atmosphere. However, accidental spills or hazardous releases must be reported. Potential emissions include:

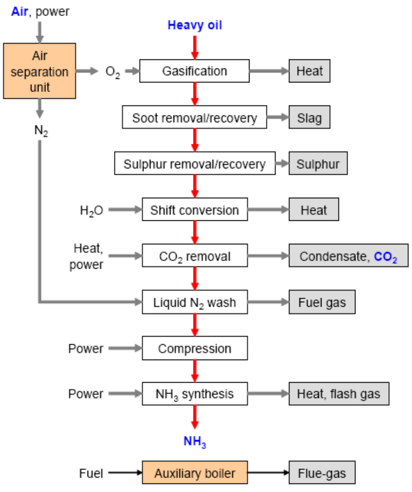
- ***Air gases:*** *Separated components like nitrogen and oxygen.*
- ***Impurities:*** *Naturally occurring substances in the air that are released back.*
- ***Combustion emissions:*** *Some backup systems use fired heaters, which may produce minor emissions.*

Air Separation Methods

- ***Fractional distillation:*** *The most common method.*
- ***Cryogenic air separation units (ASUs):*** *Used for producing nitrogen, oxygen, and sometimes argon.*
- ***Membrane separation:*** *Extracts a single component from the air.*
- ***Pressure swing adsorption (PSA):*** *Separates specific gases.*

- ***Vacuum pressure swing adsorption (VPSA):*** *Another method for isolating gases.*

Overall, air separation processes produce very low emissions. Some cryogenic plants use small amounts of natural gas or electricity to heat pre-purifiers, but emissions remain minimal.



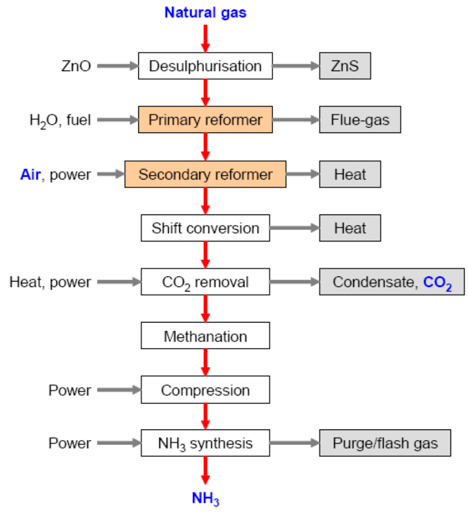
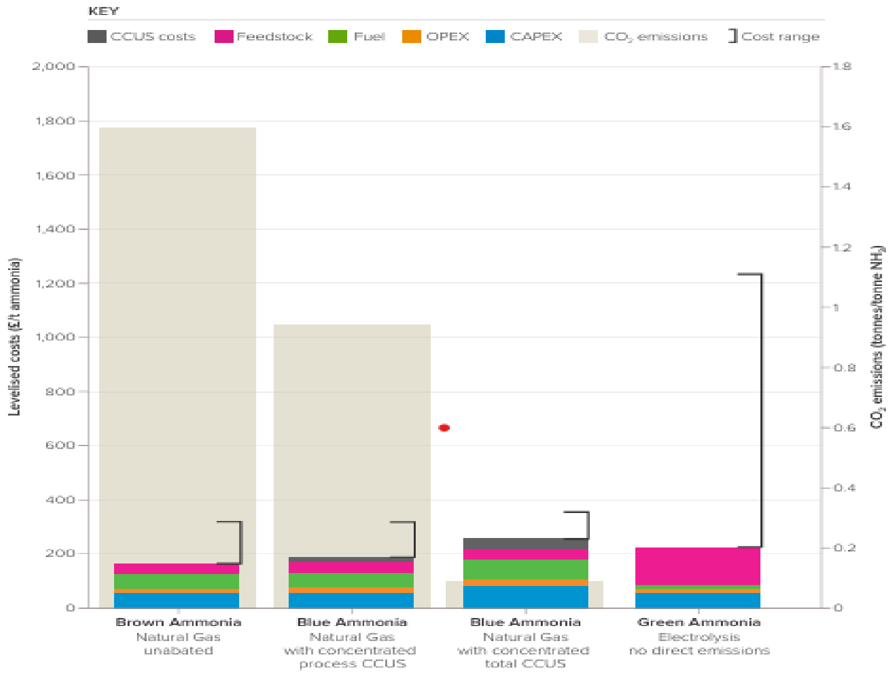


FIGURE 11

Cost comparison of ammonia production via different methods[26].



Note: Range refers to the range of total levelised costs across regions, the lower end of the range is disaggregated into cost categories. Electrolysis is assumed to be powered by 100% renewable electricity; the 'feedstock cost' is the electricity for the electrolyser, and 'fuel cost' is additional electricity for the air separation unit, synthesis loop etc. CCUS costs include capture, transport and storage of carbon dioxide; process CCUS is only process emissions; total is process and energy related emissions. % carbon dioxide reduction is relative to unabated production with natural gas (1.6 tonnes/tonne NH_3).

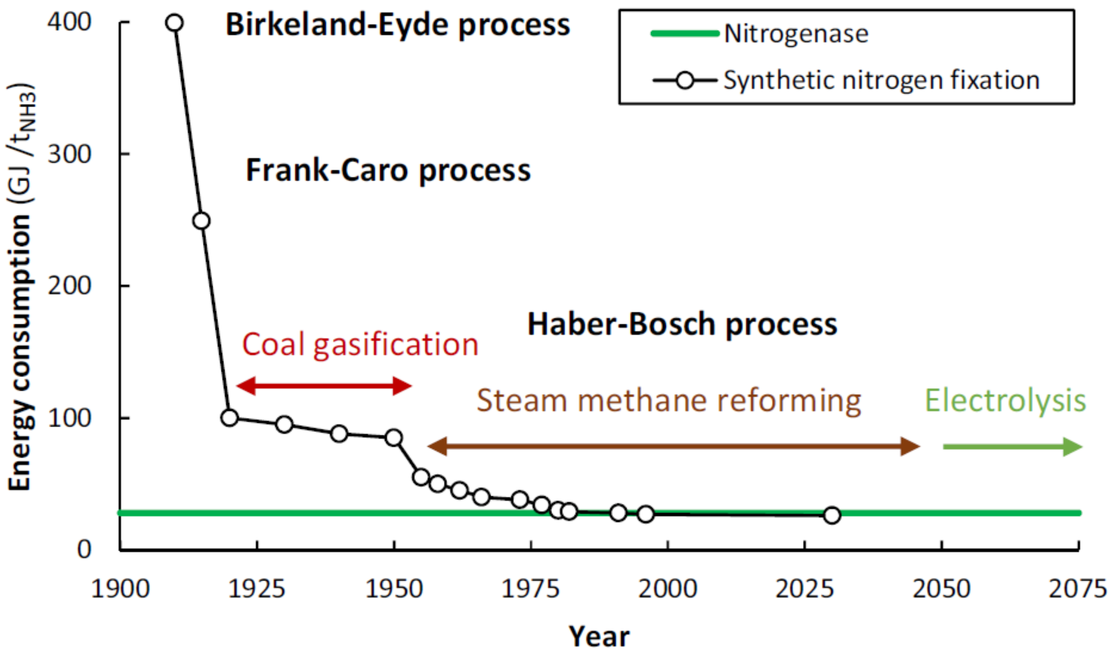


TABLE 4.2
Electrolysis Technologies.

		Alkaline	PEM	Solid Oxide
Temperature (°C)		60–90	50–80	600–1000
Pressure (bar)		1–30	10–200	1–25
System energy consumption	(GJ/t_{NH3})	29–46	31–46	24–27
Current density (A/cm)		0.2–0.45	0.6–2.0	0.3–2.0
Hydrogen purity (vol.%)		>99.5	99.99	99.9
Maximum installed capacity (MW)		165	20	0.2
Load range (%)		10–110	0–160	20–100
Installed capital cost (k€ tp/d_{NH3})	2020	165–465	365–600	935–1865
	2030	135–285	215–500	265–935
	Long term	65–235	65–300	165–335
Electrolyte		20–40 wt.% KOH	Nafion	YSZ/SSZ
System size		Large	Compact	Compact
Stack lifetime (h ×1000)	2020	60–90	30–90	10–30
	2030	90–100	60–90	40–60
	Long term	100–150	100–150	75–100
Technology readiness level (TRL)		9	8–9	5–6

Estimates based on [48,61,73,79,85–87].

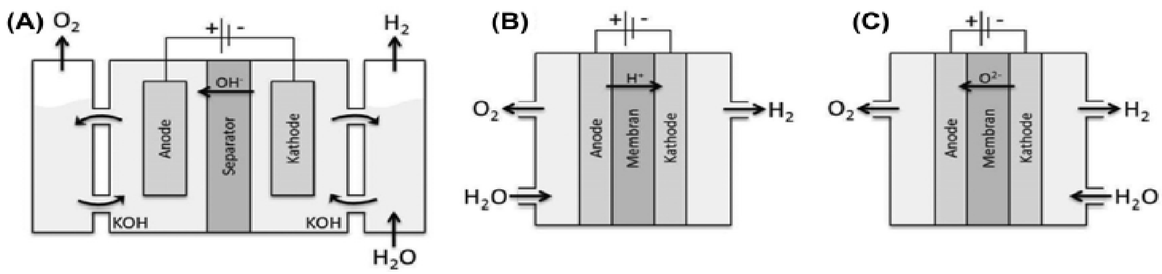


FIG. 4.7 Schematic representation of electrolysis systems: **(A)** alkaline electrolysis, **(B)** PEM electrolysis and **(C)** solid oxide electrolysis. (Reprinted from Steinmüller H, Reiter G, Tichler R, Friedl C, Furtlehner M, Lindorfer J, et al. Power to Gas - eine Systemanalyse: Markt- und Technologieschouting und -analyse [Internet]. Linz; 2014. Available from: https://www.ea.tuwien.ac.at/fileadmin/t/ea/projekte/PtG/Endbericht_-_Power_to_Gas_-_eine_Systemanalyse_-_2014.pdf with permission of TU Wien.)

Energy source	Process	Energy, $GJ\ t^{-1}_{NH3}$	CO_2 emissions, $tonnes\ t^{-1}_{NH3}$
Natural gas	Steam reforming	28	1.6
Naphtha	Steam reforming	35	2.5
Heavy fuel oil	Partial oxidation	38	3.0
Coal	Partial oxidation	42	3.8

Table 1.2 Energy needs to produce one tonne of ammonia for each route using BAT

Production route	Energy intensity (GJ/t)						Direct CO_2 intensity ($t\ CO_2/t$)
	Feedstock	Fuel	Electricity	Steam	Gross	Net	
Natural gas SMR	21.0	11.1	0.3	-4.8	32.4	27.6	1.8
Natural gas ATR	25.8	2.1	1.0	0.0	28.9	28.9	1.6
Coal gasification	18.6	15.1	3.7	-1.3	37.4	36.1	3.2
SMR with CCS	21.0	11.1	1.0	-3.1	33.1	30.0	0.1
ATR with CCS	25.8	2.1	1.5	0.0	29.4	29.4	0.1
Coal with CCS	18.6	15.1	4.9	2.6	38.6	41.2	0.2
Electrolysis	0.0	0.0	36.0	-1.6	36.0	34.4	0.0
Biomass gasification	18.6	16.5	1.4	0.0	36.5	36.5	0.0
Methane pyrolysis	40.5	0.0	8.4	-1.6	48.9	47.3	0.0

Notes: SMR = steam methane reforming; ATR = auto-thermal reforming; CCS = carbon capture and storage. All energy intensities presented for the production of 1 tonne of ammonia. The arrangements considered here include capture of both concentrated and dilute CO_2 streams. Negative values represent net steam generation, which is available for use by other process units or for export. Methane pyrolysis produces solid carbon as a by-product, the energy content of which is not reflected in the values shown. Methane pyrolysis is at an early stage of technology development and the estimates provided are for a future commercial-scale installation. CO_2 is generated from the use of bioenergy, but does not contribute towards direct CO_2 emissions from the energy system, following IEA emissions accounting conventions.

Source: Data gathered and reviewed in collaboration with the IFA and its members.

TABLE 4.1
Energy Requirement and CO_2 Footprint of Brown Ammonia, Blue Ammonia, and Green Ammonia Based on the Conventional High Pressure Ammonia Synthesis Loop. The Best Available Technology (BAT) Represents the BAT in the Year 2020, Whilst the Potential Represents the Year 2050.

	ENERGY REQUIREMENT (GJ/t_{NH3})		CO_2 FOOTPRINT (t_{CO2}/t_{NH3})		
	BAT	Potential	BAT	Potential	Relative Investment
Brown ammonia	**26**	**26**	**1.6**	**1.6**	**1.0**
SMR	26	26	1.6	1.6	1.0
Naphtha	35	–	2.5	–	1.1–1.2
Heavy fuel oil	38	–	3.0	–	1.5
Coal	42	–	3.6	–	1.8–2.1
Blue ammonia	**33**	**26**	**0.4**	**0.2**	**1.5**
Byproduct hydrogen	–	–	1.5–1.6	0.6	–
SMR with CCS	33	27	0.4	0.2	1.5
Coal with CCS	57	–	1.0–2.0	0.5	2.5–3.0
eSMR	–	26	–	1.1	1.0
Green ammonia	**33**	**26**	**0.1**	**0.0**	**1.2–1.5**
Low temperature electrolysis	33	31	0.1	0.0	1.2–1.5
High-temperature electrolysis	–	26	–	0.0	1.5–2.0
Biomass (with CCS)	–	33	1.1–1.2[a]	0.5[a]	1.2–3.0
Global average	**35**	**27**	**2.0**	**1.4**	

[a] The CO_2 emitted is part of a short carbon cycle, as opposed to the CO_2 emitted for natural gas, naphtha, heavy fuel oil, and coal feedstocks.
Estimates based on [37,42,44,50,60–62,65,66,69–72]

TABLE 3.1
DEFAULT TOTAL FUEL REQUIREMENTS (FUEL PLUS FEEDSTOCK) AND EMISSION FACTORS FOR AMMONIA PRODUCTION (PER TONNE NH_3)

Production Process	Total fuel requirement (GJ(NCV)/tonne NH_3) ± Uncertainty (%)	Carbon content factor [CCF][1] (kg/GJ)	Carbon oxidation factor [COF][1] (fraction)	CO_2 emission factor (tonnes CO_2 /tonne NH_3)
Modern plants – Europe Conventional reforming – natural gas	30.2 (± 6%)	15.3	1	1.694
Excess air reforming – natural gas	29.7 (± 6%)	15.3	1	1.666
Autothermal reforming – natural gas	30.2 (± 6%)	15.3	1	1.694
Partial oxidation	36.0 (± 6%)	21.0	1	2.772
Derived from European average values for specific energy consumption (Mix of modern and older plants) Average value – natural gas	37.5 (± 7%)	15.3	1	2.104
Average value – partial oxidation	42.5 (± 7%)	21.0	1	3.273

NCV – Net Calorific Value.

[1] Values from Energy, Vol. 2, Chapter.1, Tables 1.3 and 1.4..

Source: Adapted from EFMA (2000b; p.21); de Beer, Phylipsen and Bates (2001; p.21); for modern plants default factors can be derived using C content based on natural gas (dry basis) and partial oxidation default factors can be derived using C content based on residual fuel oil.