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Hydrogen technologies — Methodology for determining the greenhouse gas emissions associated with the production, conditioning and transport of hydrogen to consumption gate

Annex H

Hydrogen Conversion Pathway – Ammonia as a Hydrogen Carrier

Contents

Annex H
(informative)

Hydrogen Conversion Pathway – Ammonia as a Hydrogen Carrier

H.1 Process description and overview

Sections H.1.1 and H.1.2 provide a description and an overview for ammonia as hydrogen carrier.

H.1.1 Description

Worldwide, ammonia (NH_3) is currently used primarily as a fertilizer or feedstock for chemical production and is of growing interest as a carrier of hydrogen and fuel. Advantages of ammonia as a hydrogen carrier include its volumetric hydrogen density (99 kgH_2/m^3 in liquid form, at room temperature and 10 bar),[1,2] which is greater than liquid hydrogen, and that it liquefies at room temperature at modest pressure (~10 bar).[3] High density is desirable among hydrogen carriers to reduce the space requirements for delivery vessels and potentially reduce cost. Additionally, a high boiling point reduces the potential for boil-off losses that otherwise increase the delivery cost. Ammonia is typically produced via the Haber Bosch process, combining nitrogen and hydrogen over catalyst beds at elevated temperature and pressure. The hydrogen can be supplied via independent hydrogen production facilities (e.g., electrolyzers, industrial co-product streams, etc.) or produced by reforming or cracking natural gas or biogas, or by hydrocarbon gasification pathways that are closely integrated with the Haber Bosch process.

About 70% of ammonia production today relies on natural gas feedstock as the hydrogen supply source, and approximately 20% relies on coal.[4] Biogas can also be used in ammonia production in pathways very similar to those that depend on conventional natural gas. Low emission Pathways to ammonia production may include carbon capture and sequestration in conjunction with carbon-based feedstock, and pathways that use hydrogen with diminished GHG's emissions, produced at independent facilities such as via electrolysis of water or industrial by-product. Recommended life cycle analysis methods of these pathways are described in the following sections.

Many other pathways to low emission ammonia production are currently in the R&D stages. Other pathways include the reduction of nitrogen to ammonia through electrochemical reactions in the presence of water, biological pathways, chemical looping pathways that produce ammonia as a byproduct, and the use of solid oxide electrolyzers to produce both hydrogen and nitrogen for ammonia synthesis.[5] Given the nascence of these pathways, they are not included in the current guidance.

Today, about 90% of ammonia worldwide is used as a fertilizer, and the balance is mainly used in industrial applications, such as chemical production. There is growing interest in using ammonia as a fuel and a hydrogen carrier that is ultimately cracked to release pure hydrogen. The key sources of emissions in ammonia – the production, delivery, and cracking – can be categorized into modules, described in Figure H.1 — below. This document focuses on the emissions associated with ammonia as a hydrogen carrier and considers the primary pathways/configurations likely to be encountered in that context. Modules 1-3 may be useful for other ammonia plant configurations or uses but may not be sufficient in all cases (such as hybrid low emission/conventional plants or co-product considerations).

The configurations of ammonia production plants vary widely, and hydrogen production can be closely integrated with ammonia production. If hydrogen is produced independent of the ammonia production

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1 https://www.frontiersin.org/articles/10.3389/fenrg.2021.580808/full
2 https://pubs.acs.org/doi/10.1021/acsenergylett.1c02189
3 https://www.cell.com/joule/pdf/S2542-4351(20)30173-2.pdf
4 https://pubs.rsc.org/en/content/articlelanding/2020/gc/d0gc02301a
5 https://royalsociety.org/-/media/policy/projects/green-ammonia/green-ammonia-policy-briefing.pdf

process, the emissions associated with Module 1 should be calculated per the Annexes A to F for determining the greenhouse gas emissions associated with the production of hydrogen. Section H.1.2 describes the mechanism to characterize emissions associated with Module 3 in a scenario where hydrogen production and storage is independent.

Analysis methods to characterize Module 2 refers to section 4.3.2.6. All modules must be accounted for to depict the total life cycle emissions of ammonia used as a hydrogen carrier. As noted previously, the reporting metric corresponding to an analysis of Modules 1-5 is $kgCO_2e/kgH_2$.

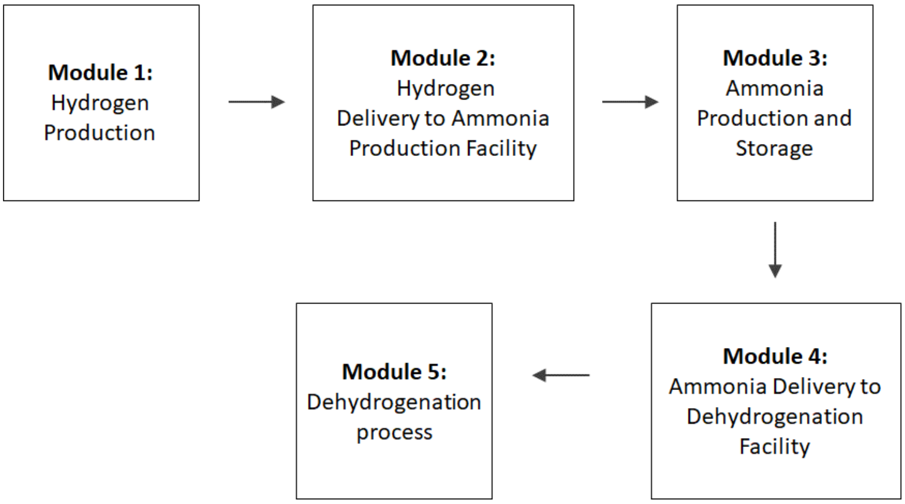

Figure H.1 —Modules for Life Cycle Analysis of Ammonia

In scenarios where ammonia is produced for direct use (e.g. as a fertilizer or fuel) rather than use as a carrier, the life cycle emissions of ammonia production could be depicted as kg CO_2e/kg NH_3 through analysis of Modules 1, 2, and 3.

After being delivered to an ammonia dehydrogenation facility, it can be decomposed or "cracked" to produce hydrogen that can then be used in its pure form. For ammonia transport emission, refer to Section 4.3.2.6. Ammonia cracking facilities are not widely utilized today but are expected to incorporate catalyst beds and high-temperature heat for decomposition. The temperature of heat required will vary widely depending on the catalyst used; values reported in the literature range from 300°C to over 1,000°C. The requisite heat can be generated via combustion of ammonia itself or combustion of part of recovered hydrogen or other fuels. An example configuration of an ammonia cracking facility is depicted in Figure H.3 —. Key emission sources within this pathway are described in Table H.2 —, and potential co-products in Table H.4.

H.1.2 Overview

Other pathways to produce ammonia include using independently produced, hydrogen that is either produced onsite or delivered. If the hydrogen is delivered, high-throughput delivery pathways, such as pipelines or transport in liquid form (e.g., in rail or marine vessels), are most likely given the significant quantity of hydrogen required at commercial ammonia plants. An example configuration of this pathway is depicted in Figure H.2 —.

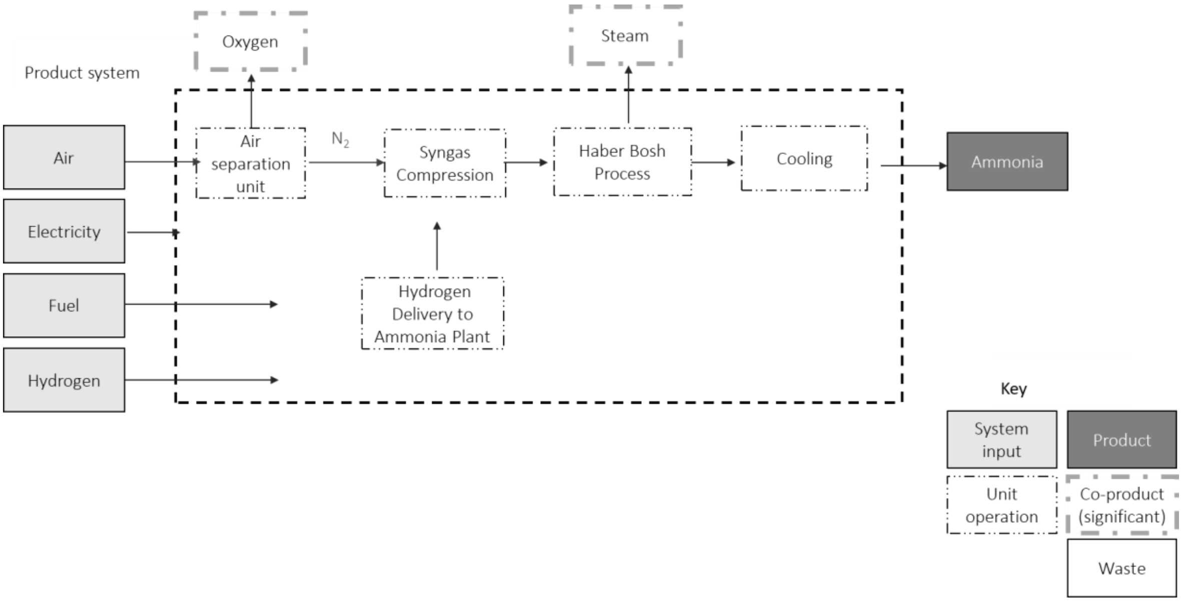

Figure H.2 —Ammonia Production from Hydrogen Adapted from Liu et al.[4]

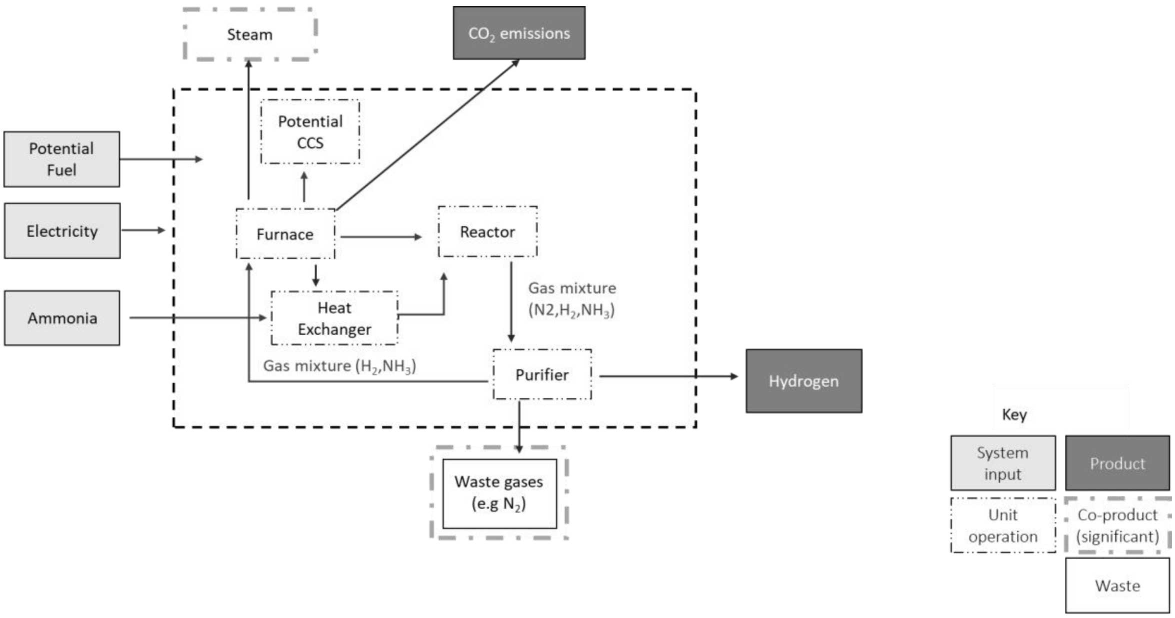

Figure H.3 —Example Pathway for Ammonia Cracking to Produce Hydrogen, adapted from numerous sources. [6,7,8]

Parameters that may vary in real-world facilities include the fuel source (e.g., in many facilities, ammonia may be combusted for heat generation or electric furnaces may be used rather than combustion of

[6] https://www.energy.gov/sites/prod/files/2015/01/f19/fcto_nh3_h2_storage_white_paper_2006.pdf
[7] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/880826/HS420_-_Ecuity_-_Ammonia_to_Green_Hydrogen.pdf
[8] https://escholarship.org/content/qt7z69v4wp/qt7z69v4wp_noSplash_db283f1adaa653e9f3ffd0095a664b3f.pdf

separate heating fuel), and the degree of waste gas formation, which will be influenced by the catalyst used and operating temperature.

H.2 Emission sources and inventory

Key drivers of GHG emissions in ammonia production using hydrogen feedstock are described in Table H.1. Potential co-products are described in Table H.2.

Table H.1 — Key Emissions from ammonia production, transport and storage from Hydrogen

Process unit/stage	Key emissions sources	Secondary Emission Sources
Hydrogen production	• Emissions will be dependent on the production pathway, based on the ISO TS 19870.	
Hydrogen delivery	• Electricity/fuel consumption for hydrogen conditioning and transport to ammonia plants •	
Air separation unit	• Electricity consumption	
Compression of syngas, nitrogen, and/or hydrogen	• Electricity consumption • Fugitive emissions	
Haber-Bosch Process	• Electricity/fuel consumption • Fugitive emissions	
Cooling	• Electricity consumption	
Ammonia transport	• Electricity/fuel consumption • Fugitive emissions	
Ammonia Storage	• Electricity/fuel consumption • Fugitive emissions	

Table H.2 — Key Emission Sources Associated with Ammonia Cracking

Process unit/stage	Key emissions sources	Secondary emissions sources
Furnace	• Electricity consumption • Production of heating fuel (e.g., natural gas) • Delivery of heating fuel to cracking facility, including fugitive emissions and electricity or fuel consumed in transport (e.g., via pipelines or trucks) [9] • Fugitive GHG emissions of heating fuel at cracking facility CO_2 released by the furnace	
CO_2 capture (if used)	• Electricity and/or heat used in CO_2 capture units	

[9] In some cases, the heating fuel used may not be a fossil fuel. For instance, waste heat from nearby industrial processes may be used, or some of the hydrogen produced via cracking may be used. If waste heat (that would otherwise be rejected to the atmosphere) is utilized, its emissions intensity may be treated as 0. If hydrogen is utilized, its emissions should be represented using the current document.

	• Residual CO_2 which is not captured for permanent storage	
Compression for transport of CO_2 (if used)	• Electricity for compression of CO_2 • Electricity and/or gaseous fuel combustion for pipeline transport • Fuel combustion for motive transport • Fugitive CO_2 emissions	
Storage of CO_2 (if included)	• Electricity/fuel use for storage compression and injection or transformation	Fugitive CO_2 emissions from a permanent storage location
Compression of ammonia, nitrogen, hydrogen, or gas mixtures	• Electricity consumption • Fugitive emissions	
Heat exchanger	• Electricity consumption	
Purifier	• Electricity consumption	

H.3 Emission Allocation

Table H.3 — and Table H.4 —provide information for emission allocation for ammonia production from hydrogen and ammonia cracking into hydrogen.

Table H.3 — Potential co-products and Emissions Accounting Framework for Ammonia Production from Hydrogen

Step	**Potential co-product**	**Recommended approach to emissions accounting**
Air separation unit	Oxygen Argon	Use of allocation factors specified in database or by LCA. Regarding allocation for ASU, if it's inside the system boundary, use mass allocation. Or, if it is outside of the system boundary, it should be considered as an upstream emission factor.
Ammonia production	Steam	Subdivision by systems when feasible

Table H.4 — Potential Co-Products Associated with Ammonia Cracking

Process unit/stage	**Potential Co-Product**	**Recommended Emissions Accounting Method**
Furnace	Steam	Subdivision by systems when feasible
Purifier	Nitrogen	System Expansion (consequential approach)

H.4 Information to be reported

Table H.5 and Table H.6 describe reporting requirements for ammonia production and cracking facilities.

Table H.5 — Information to be reported for Ammonia Production

Category	Parameters to Report
Facility details	• Facility identity • Facility location • Facility capacity • Commencement of facility operation
Product specification	• Ammonia produced (kg) • Ammonia temperature and pressure at gate • Ammonia purity level at the gate [%] • Specification of contaminants
GHG emissions overview	• Emissions intensity of ammonia production process ($kgCO_2e/kgNH_3$ produced)
Batch details	• Beginning and end of batch dates • Batch quantity
Electricity	Location-based emissions accounting: • Quantity of purchased grid electricity [kWh] • Location based emission factor used [gCO_2e/kWh] Market-based emissions accounting • Quantity of purchased grid electricity [kWh] • Quantity of contracted electricity [kWh] and/or quantity of associated GOs or RECs • Type of GOs or RECs • Residual electricity • Residual mix emission factor [gCO_2e/kWh] On-site electricity generation • Quantity of on-site generation [kWh] • Emission factor for on-site generation (as applicable) [gCO_2e/kWh]
Hydrogen	• Emissions intensity of hydrogen being utilized (calculated via guidance of this document) ($kgCO_2e$/kgH2)
Waste and other Co-products	• Quantity of steam produced [kg] • Quantity of steam sold [kg] • Emissions allocated to steam [$kgCO_2e$] • Quantity of oxygen produced (kg) • Quantity of oxygen sold (kg) • Emissions allocated to oxygen[$kgCO_2e$]

Table H.6 — Information to be reported for Ammonia Cracking

Category	Parameters to Report
Facility details	• Facility identity • Facility location • Facility capacity [t/year] • Commencement of facility operation
Input Specification	• Ammonia quantity [kg]
Product specification	• Hydrogen produced [kg] • Hydrogen pressure level at the gate • Hydrogen purity level at the gate [%] • Specification of contaminants

GHG emissions overview	• Emissions intensity of cracking process per kilogram of hydrogen produced [kgCO_2e/kgH_2 produced]
Batch details	• Beginning and end of batch dates • Batch quantity
Electricity	Location-based emissions accounting: • Quantity of purchased grid electricity [kWh] • Location based emission factor used [gCO_2e/kWh] Market-based emissions accounting • Quantity of purchased grid electricity [kWh] • Quantity of contracted electricity [kWh] and/or quantity of associated GOs or RECs • Type of GOs or RECs • Residual electricity • Residual mix emission factor [gCO_2e/kWh] On-site electricity generation • Quantity of on-site generation [kWh] • Emission factor for on-site generation (as applicable) [gCO_2e/kWh]
Other utilities	• Source/s of steam • Quantity of purchased steam [kg] • Quantity of steam exported [kg]
Fuel feedstock	• Types of fuels combusted • Quantities of fuel combusted [L, kg] • Relevant emissions calculations and factors used
Waste and/or co-products	• Quantity of steam produced [kg] • Quantity of steam sold [kg] • Emissions allocated to steam [kgCO_2e] • Quantity of nitrogen produced (kg) • Quantity of nitrogen sold (kg) • Emissions allocated to nitrogen [kgCO_2e]
Carbon dioxide treatment	• Type of CO_2 storage • Location of CO_2 storage • Transport type of CO_2 to a storage location (if applicable) • Quantity of CO_2 captured [kg] • Quantity of CO_2 stored [kg] • Quantity of CO_2 sold [kg] • Quantity of fugitive emissions created during injection of CO_2 into the storage location [kg] • Quantity of fugitive CO_2 emissions from storage [kg] (in line with the period covered by the reporting)