



DPC: 25/30487725 DC

BSI Group Headquarters

389 Chiswick High Road London W4 4AL

Tel: +44 (0)20 8996 9000

Fax: +44 (0)20 8996 7400

www.bsigroup.com

Date: 05 May 2025

Origin: European

Latest date for receipt of comments: 28 June 2025

Project No. 2024/00493

Responsible committee: GSE/6

Interested committees:

Title: BS EN ISO 19870-1 Draft Hydrogen technologies - Methodology for determining the greenhouse gas emissions associated with the hydrogen supply chain. Part 1: Emissions associated with the production of hydrogen to production gate.

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Introduction

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For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



DRAFT International Standard

ISO/DIS 19870-1

Hydrogen technologies — Methodology for determining the greenhouse gas emissions associated with the hydrogen supply chain —

Part 1: Emissions associated with the production of hydrogen to production gate

ICS: 27.075; 13.020.40

This document is circulated as received from the committee secretariat.

ISO/CEN PARALLEL PROCESSING

Reference number
ISO/DIS 19870-1:2025(en)

Full document details: 25/30487725 DC

ISO/TC 197/SC 1

Secretariat: **SCC**

Voting begins on:
2025-05-05

Voting terminates on:
2025-07-28

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CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies*, Subcommittee SC 1, *Hydrogen at scale and horizontal energy systems*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

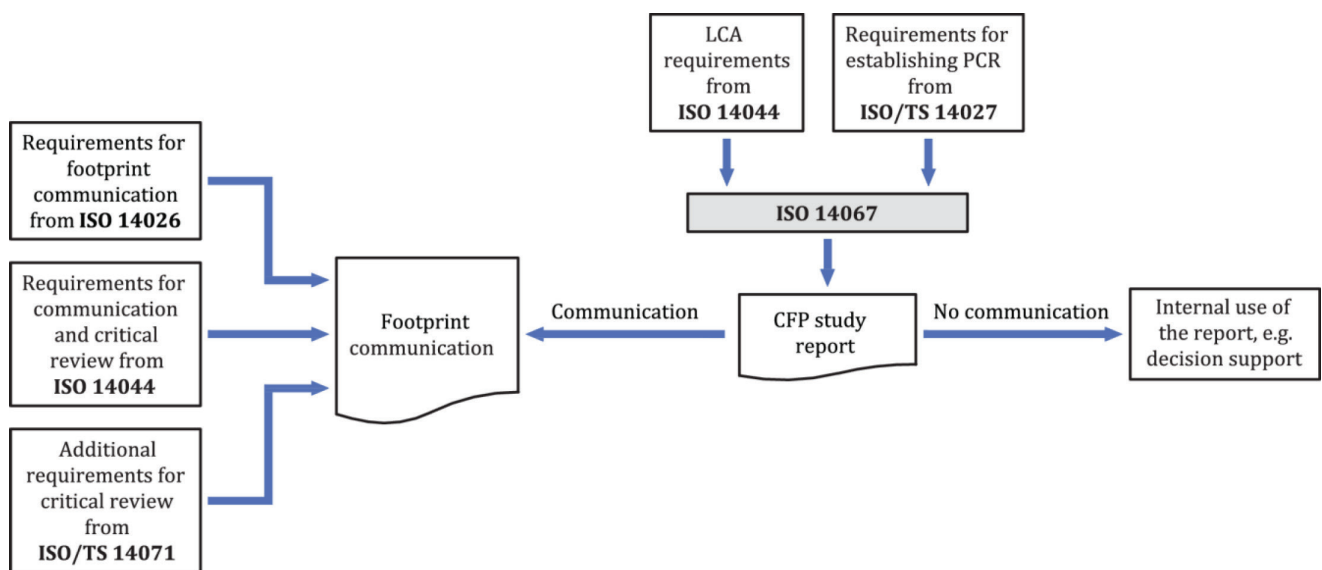
The Paris Agreement was adopted at the UN Climate Change conference (COP21) with the aims of: strengthening the global response to the threat of climate change, restricting global temperature rise to below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1,5 °C above pre-industrial levels. To meet these goals, greenhouse gas (GHG) emissions need to be reduced by about 45 % from 2010 levels by 2030, reaching net zero in 2050 (IPCC, 2018; UNFCCC, 2021).

GHG initiatives on mitigation rely on the quantification, monitoring, reporting and verification of GHG emissions and/or removals. International Standards that support the transformation of scientific knowledge into tools can help in reaching the targets of the Paris Agreement to address climate change.

ISO 14044 defines the requirements and guidelines identified in existing International Standards on life cycle assessment (LCA). The ISO 14060 series provides clarity and consistency for quantifying, monitoring, reporting and validating or verifying GHG emissions and removals to support sustainable development through a low-carbon economy. It also benefits organizations, project proponents and stakeholders worldwide by providing clarity and consistency on quantifying, monitoring, reporting and validating or verifying GHG emissions and removals.

ISO 14067 is based on the requirements and guidelines on LCA identified in ISO 14044 and aims to set specific requirements for the quantification of a carbon footprint (CFP) and a partial CFP. ISO 14067 defines the principles, requirements and guidelines for the quantification of the carbon footprint of products. Its aim is to quantify GHG emissions associated with the lifecycle stages of a product, beginning with resource extraction and raw material sourcing and extending through the production, use and end-of-life stages of the product.

[Figure 1](#) illustrates the relationship between ISO 14067 and other ISO documents on LCA.



PCR: Product category rule

Figure 1 — Relationship between standards beyond the GHG management family of standards (source ISO 14067:2018)

Hydrogen can be produced from diverse sources including renewables, nuclear and fossil fuels, with or without carbon capture, utilization and storage (CCUS). Hydrogen can be used to decarbonize numerous sectors.

A particular challenge is that identical hydrogen molecules can be produced and combined from sources that have different GHG intensities. Similarly, hydrogen-based fuels and derivatives will be indistinguishable and can be produced from hydrogen combined with a range of fossil and low-carbon inputs. Indeed,

some of the products made from hydrogen (e.g. electricity) can themselves be used in the production of hydrogen. Accounting standards for different sources of hydrogen along the supply chain (see [Figure 2](#)) will be fundamental to create a market for low-carbon hydrogen, and these standards need to be agreed upon internationally. Additionally, there is the possibility that consumption gates are not located in proximity to hydrogen production gates, requiring hydrogen transport. ISO 14083 gives guidelines for the quantification and reporting of GHG emissions arising from transport chain operations.

A mutually recognized international framework that is robust, and that avoids miscounting or double counting of environmental impacts is needed. Such a framework will provide a mutually agreed upon approach to “guarantees” or “certificates” of origin, and will cover greenhouse gas inputs used for hydrogen production, conditioning, conversion and transport.

The series of international standards ISO 19870 aims at establishing methodologies that should be applied, in line with ISO 14067, to the specific case of the hydrogen value chain, covering different production processes and other parts of the value chain, such as conditioning hydrogen in different physical states, conversion of hydrogen into different hydrogen carriers and the subsequent transport up to the consumption gate. This document, ISO 19870-1 considers the steps up to the production gate.

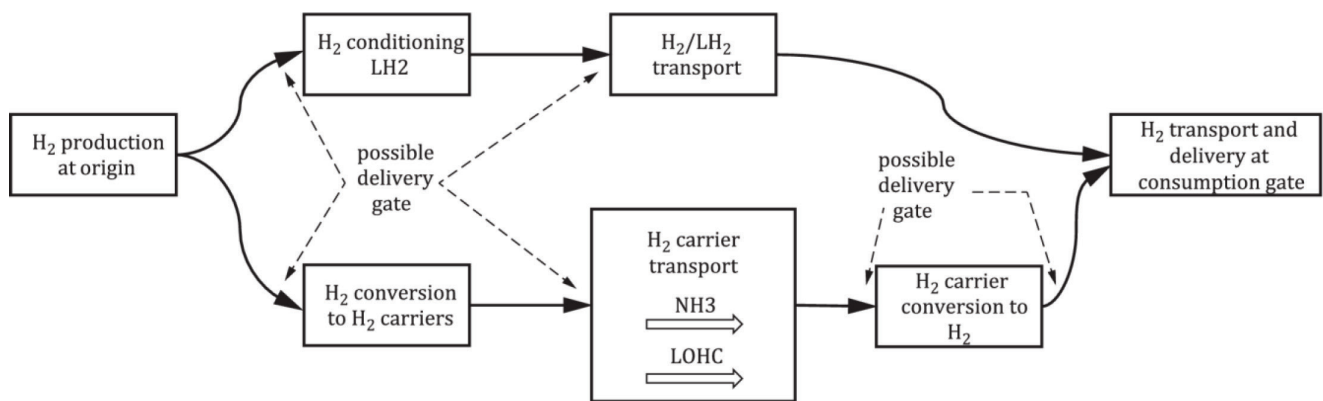


Figure 2 — Examples of hydrogen supply chain

Hydrogen technologies — Methodology for determining the greenhouse gas emissions associated with the hydrogen supply chain —

Part 1: Emissions associated with the production of hydrogen to production gate

1 Scope

ISO 14044 requires the goal and scope of an LCA to be clearly defined and be consistent with the intended application. Due to the iterative nature of LCAs, it is possible that the LCA scope needs to be refined during the study.

The goals and scopes of the methodologies correspond to either approach a) or b), given below, that ISO 14040:2006, Annex A2 gives as two possible approaches to LCAs.

- a) An approach that assigns elementary flows and potential environmental impacts to a specific product system, typically as an account of the history of the product. See [Section 4.1.2](#).
- b) An approach that studies the environmental consequences of possible (future) changes between alternative product systems. See [Section 4.1.3](#).

In this document, approach (a) is referred to as an *attributitional approach*, while approach (b) is referred to as a *consequential approach*. Complementary information is accessible in the ILCD handbook^[4].

A Carbon Footprint of a Product ([3.1.2](#)) or Partial Carbon Footprint of a Product ([3.1.3](#)) as defined by ISO 14067 may be estimated using either the attributitional or the consequential approach, the latter corresponding to the use of “system expansion via substitution” to avoid allocation when a unit process yields multiple co-products. This document applies to the CFP for hydrogen production.

There are numerous pathways to produce hydrogen. This document describes in the annexes the requirements and evaluation methods applied to several hydrogen production pathways of interest.

This document considers the GHG emissions associated with hydrogen production up to the production gate. This document applies to and includes every steps within the production process up to the production gate (see [Figure 2](#) in the Introduction).

Complementary documents in the ISO 19870-X series will consider hydrogen conditioning, conversion and transport methods.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14040:2006, *Environmental management — Life cycle assessment — Principles and framework*

ISO 14044, *Environmental management — Life cycle assessment — Requirements and guidelines*

ISO 14067:2018, *Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification*

ISO 14083:2023, *Greenhouse gases — Quantification and reporting of greenhouse gas emissions arising from transport chain operations*

ISO/TS 14071, *Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1 Quantification of the Carbon Footprint of a Product

3.1.1

allocation

partitioning the *input* (3.2.8) or *output* (3.2.10) flows of a process or a *product system* (3.2.3) between the product system under study and one or more other product systems

[SOURCE: ISO 14040:2006 and ISO 14040:2006/AMD 1:2020]

3.1.2

carbon footprint of a product

CFP

sum of *greenhouse gas emissions* (3.1.12) and *greenhouse gas removals* (3.1.4) in a *product system* (3.2.3), expressed as *CO₂ equivalent* (3.1.10) and based on a life cycle assessment (3.4.5) using the single impact category of climate change

Note 1 to entry: A CFP can be disaggregated into a set of figures identifying specific *GHG emissions* (3.1.12) and *removals* (3.1.4). A CFP can also be disaggregated into the stages of the life cycle (3.4.4).

Note 2 to entry: The results of the *quantification of CFP* (3.1.8) are documented in the CFP study report expressed in mass of *CO₂e* (3.1.11) per *functional unit* (3.2.14).

[SOURCE: ISO 14067:2018, 3.1.1.1]

3.1.3

partial CFP

sum of *greenhouse gas emissions* (3.1.12) and *greenhouse gas removals* (3.1.4) of one or more selected process(es) in a *product system* (3.2.3) expressed as *CO₂ equivalents* (3.1.10) and based on the selected stages or processes within the life cycle (3.4.4)

Note 1 to entry: A partial CFP is based on or compiled from data related to (a) specific process(es) or footprint information modules (defined in ISO 14026:2017, 3.1.4), which is (are) part of a *product system* (3.2.3) and can form the basis for quantification of a carbon footprint of a product (CFP). More detailed information on information modules is given in ISO 14025:2006, 5.4.

Note 2 to entry: The results of the quantification of the partial CFP are documented in the CFP study report expressed in mass of *CO₂e* (3.1.10) per declared unit.

Note 3 to entry: In this document, partial CFP of hydrogen is extends from raw material extraction up to the production gate.

3.1.4

greenhouse gas removal

GHG removal

withdrawal of a *greenhouse gas* ([3.1.9](#)) from the atmosphere

[SOURCE: ISO 14067:2018, 3.1.2.6]

3.1.5

CFP study

all activities that are necessary to quantify and report the *carbon footprint of a product* ([3.1.2](#)) or a *partial CFP* ([3.1.3](#))

[SOURCE: ISO 14067:2018, 3.1.1.4]

3.1.6

product category

group of products that can fulfil equivalent functions

[SOURCE: ISO 14025:2006, 3.12]

3.1.7

production batch

amount of products produced by a device between any two points in time selected by the operator

3.1.8

quantification of CFP

activities that result in the determination of the *carbon footprint of a product* ([3.1.2](#)) or a *partial CFP* ([3.1.3](#))

Note 1 to entry: Quantification of the *carbon footprint of a product* ([3.1.2](#)) or the *partial CFP* ([3.1.3](#)) is part of the *CFP study* ([3.1.5](#))

[SOURCE: ISO 14067:2018, 3.1.1.6]

3.1.9

greenhouse gas

GHG

gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds

Note 1 to entry: For a list of *greenhouse gases* ([3.1.9](#)), see the latest IPCC Assessment Report.

Note 2 to entry: Water vapour and ozone, which are anthropogenic as well as natural *greenhouse gases* ([3.1.9](#)), are not included in the *carbon footprint of a product* ([3.1.2](#)).

Note 3 to entry: The focus of this document is limited to long-lived GHGs and it therefore excludes climate effects due to changes in surface reflectivity (albedo) and short-lived radiative forcing agents (e.g. black carbon and aerosols).

[SOURCE: ISO 14067:2018, 3.1.2.1]

3.1.10

carbon dioxide equivalent

CO₂ equivalent

CO₂e

unit for comparing the radiative forcing of a *greenhouse gas* ([3.1.9](#)) to that of carbon dioxide

Note 1 to entry: Mass of a greenhouse gas is converted into *CO₂ equivalents* by multiplying the mass of the *greenhouse gas* ([3.1.9](#)) by the corresponding *global warming potential* ([3.1.11](#)) or global temperature change potential (GTP) of that gas.

Note 2 to entry: In the case of GTP, *CO₂ equivalent* is the unit for comparing the change in global mean surface temperature caused by a greenhouse gas to the temperature change caused by carbon dioxide.

[SOURCE: ISO 14067:2018, 3.1.2.2]

3.1.11
global warming potential
GWP

index, based on radiative properties of *greenhouse gases* (3.1.9) (GHG) measuring the radiative forcing following a pulse emission of a unit mass of a given GHG in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide (CO₂)

Note 1 to entry: “Index” as used in this document is a “characterization factor” as defined in ISO 14040:2006, 3.37.

Note 2 to entry: A “pulse emission” is an emission at one point in time.

[SOURCE: ISO 14067:2018, 3.1.2.4]

3.1.12
greenhouse gas emission
GHG emission

release of a *greenhouse gas* (3.1.9) into the atmosphere

[SOURCE: ISO 14067:2018, 3.1.2.5]

3.1.13
greenhouse gas emission factor
GHG emission factor

coefficient relating activity data with the *greenhouse gas emission* (3.1.3)

[SOURCE: ISO 14067:2018, 3.1.2.7]

3.1.14
capital goods emission
CAPEX emission

GHG emissions (3.1.12) related to the manufacturing of capital goods

3.1.15
subdivision
virtual subdivision

decomposition of a unit process into physically or virtually distinguishable sub-process steps with the possibility to collect data exclusively for those sub-processes

3.1.16
hydrogen

gas mainly composed of hydrogen molecules.

Note 1 to entry: hydrogen molecule is referred as H₂.

3.1.17
physical relationship

relation between *co-products* (3.2.4) based on a chosen physical characteristic (e.g., mass, energy content, volume). A physical relationship can be used (1) to allocate input flows to *co-products* (3.2.4) based on the specific function the inputs perform in relation to the individual *co-products* (3.2.4) and/or (2) to allocate *GHG emissions* (3.1.12) to the individual *co-products* (3.2.4)

3.2 Products, product systems and processes

3.2.1
product
any goods or service

Note 1 to entry: The product can be categorized as follows:

- services (e.g. transport);
- software (e.g. computer program, dictionary);

- hardware (e.g. engine mechanical part);
- processed materials (e.g. lubricant).

[SOURCE: ISO 14040:2006, 3.9]

3.2.2

product flow

products ([3.2.1](#)) entering from or leaving to another *product system* ([3.2.3](#))

[SOURCE: ISO 14040:2006, 3.27]

3.2.3

product system

collection of unit processes with *elementary flows* ([3.2.16](#)) and *product flows* ([3.2.2](#)), performing one or more defined functions and which models the life cycle ([3.4.4](#)) of a *product* ([3.2.1](#))

[SOURCE: ISO 14044:2006, 3.28]

3.2.4

co-product

one of two or more *products* ([3.2.1](#)) coming from the same unit process or *product system* ([3.2.3](#)) that is not considered *waste* ([3.3.15](#))

[SOURCE: modified from ISO 14040:2006, 3.10]

3.2.5

conditioning

means changing the physical conditions (e.g. temperature, pressure) of hydrogen for the purpose of its storage or transport

Note 1 to entry: In this document, examples are changing the pressure of gaseous hydrogen or liquefying gaseous hydrogen.

3.2.6

conversion

means changing the chemical conditions of a chemical species

3.2.7

heating value

amount of energy released when a fuel is burned completely

Note 1 to entry: Care must be taken not to confuse higher heating values (HHVs) and lower heating values (LHVs).

3.2.8

input

product ([3.2.1](#)), material or *energy flow* ([3.2.17](#)) that enters a unit process

Note 1 to entry: *Products* ([3.2.1](#)) and materials include raw materials, *intermediate products* ([3.2.9](#)) and *co-products* ([3.2.4](#)).

[SOURCE: ISO 14040:2006, 3.21]

3.2.9

intermediate product

output from a unit process that is input to other unit processes that requires further transformation within the system

[SOURCE: ISO 14040:2006, 3.23]

3.2.10

output

product ([3.2.1](#)), material or *energy flow* ([3.2.17](#)) that leaves a unit *process* ([3.2.13](#))

Note 1 to entry: *Products* ([3.2.1](#)), and materials include raw materials, *intermediate products* ([3.2.9](#)), *co-products* ([3.2.4](#)) and releases ([3.4.11](#)) .

[SOURCE: ISO 14040:2006, 3.25]

3.2.11

system boundary

boundary based on a set of criteria representing which unit *processes* ([3.2.13](#)) are a part of the system under study

[SOURCE: ISO 14040:2006/AMD 1:2020, 3.32]

3.2.12

system expansion

concept of expanding the *product system* ([3.2.3](#)) to include additional functions related to the *co-products* ([3.2.4](#))

Note 1 to entry: The *product system* ([3.2.3](#)) that is substituted by the *co-product* ([3.2.4](#)) is integrated in the *product system* ([3.2.3](#)) under study. In practice, the *co-products* ([3.2.4](#)) are compared to other substitutable products, and the environmental burdens associated with the substituted product(s) are subtracted from the *product system* ([3.2.3](#)) under study. The identification of this substituted system is done in the same way as the identification of the upstream system for *intermediate product* ([3.2.9](#)) *inputs* ([3.2.8](#)). See also ISO/TR 14049:2012, 6.4

Note 2 to entry: The application of *system expansion* ([3.2.12](#)) involves an understanding of the market for the *co-products* ([3.2.4](#)). Decisions about *system expansion* ([3.2.12](#)) can be improved through understanding the way *co-products* ([3.2.4](#)) compete with other products, as well as the effects of any product substitution upon production practices in the industries impacted by the *co-products* ([3.2.4](#)).

Note 3 to entry: Can be referred to as *system expansion* ([3.2.12](#)) and also as expanding the *system boundary* ([3.2.11](#)).

[SOURCE: ISO 14044:2006/AMD 2:2020, D.2.1]

3.2.13

process

set of interrelated or interacting activities that transforms *inputs* ([3.2.8](#)) into *outputs* ([3.2.10](#))

[SOURCE: ISO 14044:2006, 3.11]

3.2.14

functional unit

quantified performance of a *product system* ([3.2.3](#)) for use as a reference unit

Note 1 to entry: As the carbon footprint of a product treats information on a product basis, an additional calculation based on a declared unit can be presented.

[SOURCE: ISO 14040:2006, 3.20]

3.2.15

elementary flow

material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation

Note 1 to entry: "Environment" is defined in ISO 14001:2015, 3.2.1.

[SOURCE: ISO 14044:2006, 3.12]

3.2.16**energy flow**

input ([3.2.8](#)) to or *output* ([3.2.10](#)) from a unit process or *product system* ([3.2.3](#)), quantified in energy units

Note 1 to entry: Energy flow that is an input can be called an energy input; energy flow that is an output can be called an energy output.

[SOURCE: ISO 14040:2006, 3.13]

3.2.17**feedstock**

any material input to the hydrogen plant that is not generated at the hydrogen plant itself. A non-exhaustive list may include

- Natural gas (e.g. for steam methane reforming)
- Biomethane/Renewable Natural Gas¹⁾ (e.g. for steam methane reforming)
-
- Biomass
- Coal (e.g. for gasification)
- Liquid Hydrocarbons (e.g. for catalytic reforming of naphtha)
- Biogenic Waste (e.g. for gasification)
- Non-biogenic Waste (e.g. for gasification)
- Oxygen (e.g. for autothermal reforming)
- Water (e.g. for water electrolysis)
- Steam

If a hydrogen plant both generates and utilizes a material (e.g. steam), only the portion that is received by the hydrogen plant from an external source is considered to be a feedstock. For example, steam generated within the hydrogen plant system boundary for use at the hydrogen plant is not considered to be a feedstock.

3.2.18**production gate**

location of the end-outlet of the metered *product* ([3.2.1](#)) that leaves the product's production system boundary

3.2.19**delivery gate**

any location where the *product* ([3.2.1](#)) is transferred from one operator to another

3.2.20**consumption gate**

location of the final delivery of the *product* ([3.2.1](#)) to its end-use

1) In many European countries, methane sourced from the degradation of biomass under anaerobic conditions is referred to as "biomethane". In the United States, it is referred to as "Renewable Natural Gas" or "RNG".

3.3 Life Cycle Assessment

3.3.1

cut-off criteria

specification of the amount of material or *energy flow* ([3.2.17](#)) or the level of significance of *greenhouse gas emissions* ([3.1.12](#)) associated with unit processes or the *product system* ([3.2.3](#)) to be excluded from a *CFP study* ([3.1.5](#))

[SOURCE: modified from ISO 14067:2018, 3.1.4.1]

3.3.2

evaluation

element within the life cycle interpretation phase intended to establish confidence in the results of the *life cycle assessment* ([3.3.5](#))

Note 1 to entry: Evaluation includes completeness check, sensitivity check, consistency check, and any other validation that may be required according to the goal and scope definition of the study

[SOURCE: ISO 14040:2006]

3.3.3

fugitive emissions

emissions that are not physically controlled but result from the intentional or unintentional *releases* ([3.3.10](#)) of *GHGs* ([3.1.9](#))

Note 1 to entry: They commonly arise from the production, processing, transmission, storage, and use of fuels and other chemicals, often through joints, seals, packing, gaskets, etc.

[SOURCE: 2004 GHG protocol, Chapter 4.6]

3.3.4

life cycle

consecutive and interlinked stages related to a *product* ([3.2.1](#)), from raw material acquisition or generation from natural resources to end-of-life treatment

Note 1 to entry: "Raw material" is defined in ISO 14040:2006, 3.15.

Note 2 to entry: Stages of a life cycle related to a product include raw material acquisition, production, distribution, use and end-of-life treatment.

[SOURCE: ISO 14067:2018, 3.1.4.2]

3.3.5

life cycle assessment

LCA

compilation and evaluation of the *inputs* ([3.2.8](#)), *outputs* ([3.2.10](#)) and the potential environmental impacts of a *product* ([3.2.1](#)) throughout its *life cycle* ([3.3.4](#))

Note 1 to entry: "Environmental impact" is defined in ISO 14001:2015, 3.2.4.

[SOURCE: modified from ISO 14067:2018, 3.1.4.3]

3.3.6

life cycle inventory analysis

LCI

phase of *life cycle assessment* ([3.3.5](#)) involving the compilation and quantification of *inputs* ([3.2.8](#)) and *outputs* ([3.2.10](#)) for a product throughout its *life cycle* ([3.3.4](#))

[SOURCE: ISO 14044:2006, 3.3]

3.3.7

location-based method

uses the average emissions intensity of networks supplying energy commodities for consumption, such as electricity, using mostly grid-average emission factors in the location in which energy consumption occurs.

[SOURCE: modified from ISO 14064-1:2018, Annex E]

3.3.8

market-based method

a method to assign the attributes of the *product* (3.2.1) produced by a specific producer to the *product* (3.2.1) consumed by or delivered to a specific user while the *product* (3.2.1) is physically distributed through a common infrastructure.

Note 1 to entry: These choices (purchasing energy certificates or differentiated electricity product) may be reflected through contractual arrangements between the user and the producer.

3.3.9

process emissions

direct emissions within the system boundary, including emissions associated with waste treatment and disposal, such as, but not limited to, chemical conversions and combustion of solid, liquid and/or gaseous fuels or feedstock's

3.3.10

releases

emissions to air and discharges to water and soil

[SOURCE: ISO 14040:2006, 3.30]

3.3.11

sensitivity analysis

systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a *CFP study* (3.1.5)

[SOURCE: ISO 14067:2018, 3.1.4.7]

3.3.12

sensitivity check

process to determine whether the information obtained from a *sensitivity analysis* (3.3.11) is relevant for reaching the conclusions and for giving recommendations

[SOURCE: ISO 14040:2006/AMD1:2020, 3.43]

3.3.13

transparency

open, comprehensive and understandable presentation of information

[SOURCE: ISO 14040:2006, 3.7]

3.3.14

uncertainty analysis

systematic procedure to quantify the uncertainty introduced in the results of a *life cycle inventory analysis* (3.3.6) due to the cumulative effects of model imprecision, input uncertainty and data variability

Note 1 to entry: Either ranges or probability distributions are used to determine uncertainty in the results.

[SOURCE: ISO 14040:2006, 3.33]

3.3.15

waste

substances or objects that the holder intends or is required to dispose of

Note 1 to entry: This definition is taken from the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (22 March 1989), but is not confined in this document to hazardous waste.

[SOURCE: ISO 14040:2006, 3.35]

Note 2 to entry: Wastes potentially used as feedstocks for hydrogen production vary widely in composition and by region. In this document, “waste” is defined as substances or objects that the holder intends or is required to dispose of and that can be used as a feedstock for hydrogen production.

“Waste” is not necessarily a permanent designation for a material. If additional valorized product streams were to emerge for a given type of material currently deemed a waste, then competition for its use as a feedstock for hydrogen production might result in upstream emissions impacts.

To determine whether a feedstock is a waste, stakeholders should rely on analysis specific to the country the feedstock was sourced from. Such analysis should account for the quantity of the respective feedstock that is available in the host country, the approximate size of other markets for that feedstock, and the quantity of the feedstock expected to be used for hydrogen production to determine whether valorization of the waste would have occurred otherwise.

3.3.16

biogenic waste

the biogenic portion of *waste* ([3.3.15](#))

Note 1 to entry: A non-exhaustive list may include:

- The biogenic portion of municipal solid waste (MSW),
- Animal waste,
- Sewage sludge,
- Food industry residues,
- Agricultural residues,
- Food and agricultural waste (e.g., home food waste collection)
- Forests that would traditionally be left to decompose naturally (ICAO, 2019).

Whether a *product* ([3.2.1](#)) is considered a *waste* ([3.3.15](#)) or a valorized *product* ([3.2.1](#)) is based on the properties of the material (e.g., corn stover versus corn kernel). A tree intended for timber harvest may be thinned because of some perceived defect (e.g., a curved trunk, or relatively diminutive size relative to other trees in the stand). The valorization of the “waste” material which could be considered “slash and thinning” may change the decision-making of the forester regarding the disposition of woody material.

Ultimately, biomass suppliers should provide hydrogen producers with information establishing whether biomass received as a *feedstock* ([3.2.17](#)) for hydrogen production is intentionally-produced biomass or biogenic waste. A country’s legislations may encompass this definition.

3.3.17

non-biogenic waste

the non-biogenic portion of *waste* ([3.3.15](#))

Note 1 to entry: Non-biogenic waste includes content of fossil origin which is not suitable for material recovery. A non-exhaustive list may include:

- The non-biogenic portion of Municipal Solid Waste (MSW)
- The non-biogenic portion of Industrial Waste
- Plastic *waste* ([3.3.15](#)) of fossil origin (in some jurisdictions (e.g. Japan), this stream is considered to be a part of MSW)

3.4 Organizations

3.4.1 organization

person or group of people that has its own functions with responsibilities, authorities and relationships to achieve its objectives

Note 1 to entry: The concept of organization includes, but is not limited to, sole-trader, company, corporation, firm, enterprise, authority, partnership, charity or institution, or part or combination thereof, whether incorporated or not, public or private.

[SOURCE: ISO 14001:2015, Clause 4]

3.5 Data and Data Quality

3.5.1 data quality

characteristics of data that relate to their ability to satisfy stated requirements

[SOURCE: ISO 14040:2006]

3.5.2 double counting

two or more reporting entities take ownership of the same *greenhouse gas emissions* (3.1.2) or emission reductions

3.5.3 primary data

quantified value of a *process* (3.2.13) or an activity obtained from a direct measurement or a calculation based on direct measurements

Note 1 to entry: Primary data need not necessarily originate from the *product system* (3.2.3) under study because primary data might relate to a different but comparable *product system* (3.2.3) to that being studied.

Note 2 to entry: Primary data can include *greenhouse gas emission factors* (3.1.3) and/or greenhouse gas activity data (defined in ISO 14064-1:2006, 2.11).

[SOURCE: ISO 14067:2018, 3.1.6.1]

3.5.4 secondary data

data which do not fulfil the requirements for *primary data* (3.5.3)

Note 1 to entry: Secondary data can include data from databases and published literature, default emission factors from national inventories, calculated data, estimates or other representative data, validated by competent authorities.

Note 2 to entry: Secondary data can include data obtained from proxy processes or estimates.

[SOURCE: ISO 14067:2018, 3.1.6.3]

3.5.5 site-specific data

primary data (3.5.3) obtained within the *product system* (3.2.3)

Note 1 to entry: All site-specific data are *primary data* (3.5.3) but not all *primary data* (3.5.3) are site-specific data because they may be obtained from a different *product system* (3.2.3).

Note 2 to entry: Site-specific data include *greenhouse gas emissions* (3.1.12) from GHG sources as well as permanent GHG removals by GHG sinks for one specific unit process within a site.

[SOURCE: ISO 14067:2018, 3.1.6.2]

3.5.6**uncertainty**

parameter associated with the result of quantification that characterizes the dispersion of the values that could be reasonably attributed to the quantified amount

Note 1 to entry: Uncertainty can include, for example:

- parameter uncertainty, e.g. *greenhouse gas emission* (3.1.12) factors, activity data;
- scenario uncertainty, e.g. use stage scenario, end-of-life stage scenario;
- model uncertainty.

Note 2 to entry: Uncertainty information typically specifies quantitative estimates of the likely dispersion of values and a qualitative description of the likely causes of the dispersion.

[SOURCE: ISO 14067:2018, 3.1.6.4]

3.6 Abbreviated Terms

ATR	Auto thermal reforming
CCS	CO ₂ capture and storage
CCU	CO ₂ capture and utilisation
CFP	Carbon footprint of a product
CHP	Combined heat and power
CO ₂ e	Carbon dioxide equivalent
GHG	Greenhouse gas
GO	Guaranties of origin
GWP	Global warming potential
HHV	High heating value
LCA	Life cycle assessment
LCI	Life cycle inventory analysis
LHV	Low heating value
NG	Natural gas
PSA	Pressure swing adsorption
SMR	Steam methane reforming

4 Evaluation Methods**4.1 Evaluation Basis****4.1.1 General Principles**

The proposed emissions accounting methodology aims to be applicable to all hydrogen production pathways, in accordance with ISO 14040, ISO 14044, ISO 14067, ISO 14083, and using guidelines from the GHG protocols and ILCD Handbook which are based on the same ISO standards.

Therefore, referring to ISO 14067, the following criteria shall be applied for the goal and scope definition phase:

- a) the product category definition and description of the investigated pathways are identical;
- b) the declared unit is identical;
- c) the system boundary is equivalent: from raw material extraction to production gate;
- d) the description of data is equivalent;
- e) the criteria for inclusion of inputs and outputs are equivalent;
- f) the data quality requirements (e.g. transparency, coverage, precision, completeness, representativeness, consistency and reproducibility) are as consistent as technically feasible;
- g) specific GHG emissions and captures are treated identically;
- h) the units (described in Annexes) are identical.

The following criteria shall be applied for the life cycle inventory:

- i) the methods of data collection and data quality requirements are equivalent when technically feasible;
- j) the calculation procedures are identical;
- k) the allocation of the flows is consistent;
- l) the applied GWPs are identical.

The calculation method for the CFP of hydrogen can differ depending upon the intended use of the result of the evaluation. The present document describes two main situations according to ISO 14040:2006, Annex A.2. A general recommended approach is also provided in each annex. For different approaches, a justification has to be provided following a sensitivity analysis.

4.1.2 Attributional approach

An attributional approach estimates the GHG emissions occurring within the value chain of the production of hydrogen. The estimation of emissions is performed for each activity from raw material extraction to production gate, within the value chain, without considering emissions or benefits outside the scope of the analysed system. Such a case also refers to situation C2 described in the ILCD handbook.

4.1.3 Consequential approach

A consequential approach includes GHG emissions within the product system boundary, and considers possible GHG emissions that occur outside the boundaries of the product system. In this document, for a CFP, a consequential approach may be employed in the limited way corresponding to the use of “system expansion via substitution” to avoid allocation when a unit process yields multiple co-products. These co-products may displace alternatives methods of production.

Requirements for applying system expansion via substitution includes:

- The activities to be considered and the corresponding lifecycle stages for these activities shall be clearly stated in the goal and scope of the analysis.
- The counterfactual scenario according to which the consequence is evaluated shall be clearly stated in the goal and scope of the analysis.

A consequential approach may also be used for a broader impact assessment to include:

- (1) specific upstream consequences of the production,
- (2) downstream consequences of the usage of the product, or

(3) macro-economic consequences of the hydrogen production.

In all these cases, the GHG inventory is expanded beyond the boundaries of the hydrogen value chain from the raw material extraction to the production gate, considering emissions or benefits outside the boundaries of the product system. Such cases also refer to situation C1 described in the ILCD handbook. The choice of consequential approach and associated system boundaries will be defined by the goal of the analysis. These broader impacts may be considered in addition to the CFP of the product but may not be part of it within the ISO 14067 definition of CFP.

Such applications are included in [Annex B](#) - Consequential Approach Examples for Hydrogen Production.

4.2 Product reporting

4.2.1 Product System Boundary

4.2.1.1 General Principles

The “raw material extraction-to-consumption gate” system boundary is divided in three sections considering the hydrogen i) production, ii) conditioning/conversion and iii) transport, as described in [Figure 3](#).

Analysis methods described in the current document cover a “raw material extraction-to-production gate” system boundary, including direct and indirect emissions and excluding emissions deemed insignificant per [4.2.2](#). Hydrogen production CFP shall not include carbon offsetting (See ISO 14067, clause 6.3.4.1.).

Indirect emissions considered include associated impacts from the upstream activities of raw material acquisition phase, raw material transport phase, and downstream activities for discharge/disposal of waste, etc. GHG contributions are defined in terms of carbon dioxide equivalent (CO₂e).

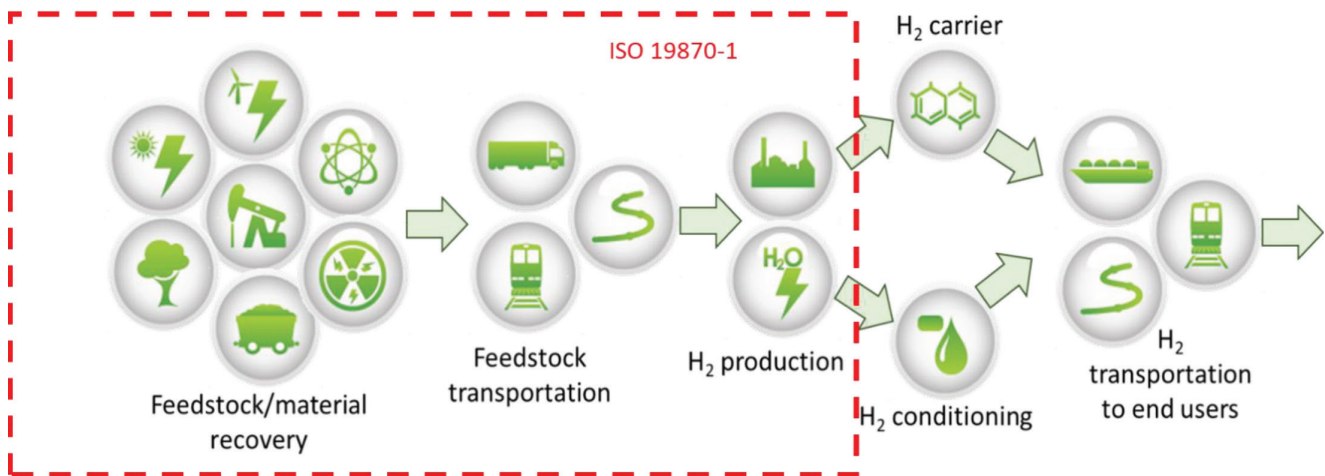


Figure 3 — Schematic of “raw material extraction to production gate” system boundary adopted for this document

The emissions from the construction, manufacturing, replacements and upgrades, and decommissioning of the capital goods (including hydrogen production device, etc.), business travel, employee commuting and upstream leased assets are not considered as normative in the raw material extraction to the production gate system boundary. The rationale for this simplification was motivated by the comparatively small contribution that these emissions add to emissions associated with fossil pathways.^[2] However, in some cases these emissions may be substantial (e.g. in the case of electrolytic hydrogen using certain types of electricity from renewable sources). Therefore, the quantification of these capital goods emissions, also known as “CAPEX emissions”, shall be provided for information separately following relevant ISO documents (e.g., ISO 14044).

The functional unit for CFP analysis of hydrogen production is established as 1 kg of hydrogen at a pressure and a purity that corresponds to the inlet requirements of the subsequent stage. As such, any leakages in

the production of hydrogen will be accounted for in the functional unit. For hydrogen purity lower than 99,9 mol%, refer to [Annex A](#). The downstream boundary limit is the production gate (3.2.23).

The reporting metric for carbon foot printing shall be $\text{kgCO}_2\text{e}/\text{kg}_{\text{hydrogen}}$ ²⁾ for hydrogen at the production gate.

4.2.1.2 Hydrogen production

There are many pathways for hydrogen production, with many different processes and technologies being proposed and implemented. This document provides details for hydrogen purity in [Annex A](#), feedstock treatment for hydrogen production in [Annex C](#) and details for specific production pathways in [Annexes D](#) to [L](#).

Emissions associated with hydrogen infrastructure past the hydrogen production gate (e.g. liquefaction, hydrogenation in a carrier) are not considered in this document but will be addressed in the ISO 19870-X series.

4.2.2 Selected Cut-Off Criteria

In general, efforts shall be taken to include all processes and flows that are attributable to the analysed system. Completeness based on environmental significance should be tested by including and excluding processes in the hydrogen production system boundary, from raw material extraction to the production gate, to determine if results change³⁾. The cut-off criteria used to exclude certain processes and flows of minor importance shall be clearly and consistently defined within the goal and scope definition phase, and, in total, shall be below $0,05 \text{ kgCO}_2\text{e}/\text{kg}_{\text{hydrogen}}$.

The final sensitivity analysis of the inputs and outputs data shall include the mass, energy and environmental significance criteria (expressed in $\text{kgCO}_2\text{e}/\text{kg}_{\text{hydrogen}}$) and all inputs not considered in the study shall be reported. For more information, see ISO 14044:2006+A2, section 4.2.3.3.3.

4.2.3 Evaluation Elements

4.2.3.1 General Principles

The CFP of produced hydrogen selects climate change as the **environmental impact category**. The characteristic factors are shown in [Table 1](#).

Table 1 — Environmental impact category, characterization model and unit

Environmental impact category	Characterization model	Unit
Climate change	Global warming potential (GWP100)	kgCO_2e

The main GHGs considered in this document are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

The global warming potential (GWP) for a 100-year period of the various greenhouse gases is expressed in kilograms of CO_2e . GWP for other time horizons and GTP, as given by the Intergovernmental Panel on Climate Change (IPCC), may be used for information in addition to GWP 100, but should be reported separately.

This document applies the latest IPCC Assessment Report recognized by the United Nations. IPCC has released updated values in AR6 WG1^[8] documents but AR5 WG1^[6] values are still the values recognised by

2) For carbon footprint in kilograms per megajoule, divide the CFP of hydrogen ($\text{kgCO}_2\text{e}/\text{kg}_{\text{hydrogen}}$) by the LHV of the hydrogen ($\text{MJ}/\text{kg}_{\text{hydrogen}}$), including impurities.

3) Completeness, as defined by ISO 14044, is based on three criteria: mass, energy and environmental significance. Application of cut-off criteria to a given value chain can rely on the following three possible quantifications:

a) Transport activity: inclusion in the study of all inputs that cumulatively contribute more than a defined percentage of the transport activity within the transport chain;
b) Energy: inclusion in the study of all inputs that cumulatively contribute more than a defined percentage of the energy activity within the value chain;
c) Environmental significance: inclusion of all GHG sources that cumulatively contribute more than a defined percentage of the GHG emissions of the value chain.

NOTE: This percentage can be specified by national regulations.

the United Nations. The other GHGs mentioned by IPCC (AR5 WG1:2013, Appendix 8.A)^[6] shall be included in the estimation of the CFP.

[Table 2](#) — shows the GWP for a period of 100 years of the main GHGs according to the Fifth Assessment Reports of the IPCC^[7].

Table 2 — Global warming potential (GWP) of selected GHGs [IPCC 2013]

	AR5 (g CO ₂ e /g species)
CO ₂	1
CH ₄	28
N ₂ O	265

Applying the GWP 100 coefficients in the IPCC Assessment Reports, the GHG emissions in kgCO₂e can be calculated by:

$$[CO_2e] = \sum_{i=1}^n P_i \times Q_i \quad (1)$$

Where [CO₂e], P_i and Q_i are, respectively, kilograms of CO₂e, kilograms of a species (i) and coefficient of a species in gCO₂e/g species (i).

The emissions from the construction, manufacturing, replacements and upgrades, and decommissioning of the capital goods (including hydrogen production device, etc.), are only considered to inform separately on the capital goods emissions. Furthermore, energy requirements and emissions resulting from the manufacturing and decommissioning of installations or applications (e.g. vehicles) consuming the hydrogen are not considered.

4.2.4 Evaluation cycle

The hydrogen considered should be evaluated for hydrogen produced in an industrial plant as the object.

The evaluation cycle constrains emissions data collection to the specified time period of hydrogen production for which the CFP is representative. The time period for which the GHG emissions are representative shall be specified and justified.

The time period of GHG emissions and captures relative to the year of production of the product shall be specified in the CFP inventory. The effect of any time difference between when GHG emissions and captures from the product system (as CO₂e) and the year of production, if calculated, shall be documented separately in the CFP study report. The method used to calculate the effect of time difference shall be stated and justified in the CFP study report. The choice of the time period for data collection should consider intra- and inter-annual variability and, when possible, use values representing the trend over the selected period. Where the GHG emissions and captures associated with specific unit processes within the CFP of a product vary over time, data shall be collected over a time period appropriate to establish the average GHG emissions and captures associated with the CFP of the product.

4.3 Quantification of GHG emissions

4.3.1 Process description and data quality

The process, methods and requirements of hydrogen production CFP quantification refer to ISO 14067:2018, Clause 5.

A description of the following items is given for each stage of the CFP of a hydrogen production pathway.

As a minimum, a) to m) shall be provided for each of the CFP of the hydrogen production stage:

- a) hydrogen process overview and description: production;
- b) emissions accounting method;

- c) emissions inventory;
- d) energy supply;
- e) upstream emissions relating to the upstream extraction of resources, when existing;
- f) emissions allocation;
- g) results of sensitivity analyses and uncertainty analysis;
- h) results of the life cycle interpretation, including conclusions and limitations;
- i) disclosure and justification of value choices that have been made in the context of decisions within the study;
- j) description of the stages of the life cycle, including a description of the selected use profiles when applicable;
- k) assessment of influence of alternative use profiles on the final results;
- l) time period for which the carbon footprint is representative;
- m) references used in the study.

The methodology should reduce bias and uncertainty by using the highest quality data available. Data quality shall be characterized by both quantitative and qualitative aspects including.

- time-related coverage: age of data and the minimum length of time over which data should be collected;
- geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the carbon footprint study;
- technology coverage: specific technology or technology mix;
- precision: measure of the variability of each data value expressed (e.g. variance);
- Accuracy referring to a qualitative assessment of the discrepancy between a measurement and the actual value
- completeness: percentage of total flow that is measured or estimated;
- representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e. geographical coverage, time period and technology coverage);
- consistency: qualitative assessment of whether or not the study methodology is applied uniformly to the various components of the sensitivity analysis;
- reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the carbon footprint study;
- sources of the data;
- uncertainty of the information.

4.3.2 Emissions inventory

4.3.2.1 General principles

An overview of the GHG emissions accounting methodology applied to each pathway is summarised below.

Total GHG emissions will be described following [Figure 3](#) as:

$$E_{total\ inventory} = E_{total\ inventory\ production} \quad (3)$$

Emissions include all direct and indirect emissions arising in the raw material extraction to production gate system boundary as defined in [4.2.1](#).

[Formula 4](#) shows the breakdown of the emissions inventory into its components (emissions categories). Individual countries may use additional emissions inventory categories that align with IPCC guidelines.

$$E_{total\ nventory} = E_{process} + E_{fugitive} + E_{other} + E_{energy\ supply} + E_{upstream} \quad (4)$$

measured in kilograms of CO₂e.

4.3.2.2 Process emissions

Process emissions are direct emissions within the hydrogen production facility, including emissions associated with waste treatment and disposal, such as, but not limited to, chemical conversions and combustion of solid, liquid and/or gaseous fuels or feedstocks including (but not limited to) coal, diesel and natural gas. They also include the GHG emissions of hydrogen that is less than 99,9 mol% pure (refer to [Annex A](#)). Process emissions can be estimated via a variety of approaches including use of emission factors and measurement of fuel (volumetric or gravimetric), and direct measurement.

Process emissions should be calculated according to [Formula 4](#):

$$E_{process} = \sum_i E_{process,i} \quad (5)$$

where $E_{process}$ is the sum of GWP-weighted emissions, according to [Table 2](#), released from the process converted into kilograms of CO₂e using [Equation 1](#). This covers combustion of solid, liquid, and gaseous fuels calculated using a variety of methods.

In the case of carbon capture, when applicable:

- for the portion of the captured CO₂ that is sequestered, it shall be considered as waste and the emissions related to capture, processing, transport and sequestration (including monitoring) shall be accounted within the inventory of emissions assigned to the production of hydrogen. To meet the requirements of "stored" CO₂, the CO₂ should be injected into qualified geologic storage facilities (e.g. as qualified by ISO 27914 and ISO 27916).
- for the portion of the captured CO₂ that is utilized, the emissions associated with its capture, processing, transport and storage (including monitoring) are allocated to the utilized CO₂ co-product following [Section 4.3.3](#).

Emissions related to CO₂ utilization shall be accounted for as follows, depending on the goal of the GHG evaluation:

- if the GHG evaluation goal is attributional (see [4.1.2](#)), the GHG emissions resulting from the use of the captured CO₂ shall not be taken into account in the inventory of emissions of the hydrogen production as they do not occur within the life cycle stage of hydrogen production. The fate of the carbon is not accounted for in the CFP of hydrogen in the attributional approach but can be accounted for using a consequential approach.
- if the GHG evaluation goal is consequential (see [4.1.3](#)), the boundaries of the system may be expanded to include other lifecycle stages of carbon where GHG emissions can be affected as a consequence of hydrogen production.

4.3.2.3 Fugitive emissions

Fugitive emissions are direct fugitive emissions within the hydrogen production facility, including emissions associated with waste treatment and disposal. Examples include but are not limited to, structural and operational losses, such as leaks and accidental losses, venting, purging as well as other losses due to plant operations. As for most hydrogen producers, fossil fuels are provided by a third-party, fugitive emissions associated with its transmission and distribution are considered in the upstream emissions. Double accounting fugitive emissions and process emissions shall be avoided.

Fugitive emissions should be calculated according to [Formula 6](#):

$$E_{\text{fugitive}} = \sum_i E_{\text{fugitive},i} \quad (6)$$

where E_{fugitive} is the sum of GWP-weighted structural and operational emissions, released from fugitives of source type (i) within the module measured and converted in kilograms of CO₂e according to [Equation 1](#).

4.3.2.4 Other emissions

Other emissions refer to the latest IPCC Assessment Report recognized by the United Nations for emissions of specific GHG gases used across several industry activities (e.g. hydrofluorocarbons (HFCs) used in industrial refrigeration and/or cooling systems, and sulphur hexafluoride (SF₆) used in electrical switchgear).

There are a variety of approaches that may be employed to estimate these emissions. Typically, this can be via assumed leakage rates, or changes in stock levels of the relevant substances as measured throughout the relevant production batch period. These items are expected to be minor sources, and estimation should be sufficient in most cases.

Other emissions should be calculated according to [Formula 7](#):

$$E_{\text{other}} = \sum_i E_{\text{other},i} \quad (7)$$

where E_{other} is the sum of GWP-weighted emissions of relevant GHG (as applicable) measured and converted to kilograms of CO₂e according to [Equation 1](#).

4.3.2.5 Energy supply

4.3.2.5.1 General principles

There are two methods to estimate the GHG emissions intensity of energy commodities connecting suppliers with consumers: (1) a location-based method and (2) a market-based method.

- (1) A location-based method reflects the average emissions intensity of networks supplying energy commodities for consumption, such as electricity, using mostly grid-average emission factors
- (2) A market-based method reflects emissions from the supply of energy that companies have purposefully chosen. It derives emission factors from contractual instruments, which include any type of contract between two parties, such as the sale and purchase of electricity, bundled with attributes about the supplied energy, or for unbundled attribute claims. Markets differ as to what contractual instruments are commonly available or used by companies to purchase energy or claim specific attributes about it, but they can include energy attribute certificates (RECs, GOs, etc.), direct contracts (e.g., renewable or low-carbon electricity, bio methane or renewable natural gas), supplier specific emission rates, and other default emission factors, e.g. representing the untracked or unclaimed electricity and emissions (termed the “residual mix”), if a company does not have other contractual information.

For the location-based emissions accounting approach, energy supply emissions should be calculated according to [Formula 8](#):

$$E_{\text{energy supply, location}} = \sum_i E_{\text{energy supply, } i} \quad (8)$$

where $E_{\text{energy supply, location}}$ is the GWP-weighted emissions, associated with supply of energy (i) (e.g. electricity, heat, steam, fuel) in kilograms of CO₂e according to [Equation 1](#) (calculated in line with the location-based approach).

For the market-based emissions accounting approach, net energy supply emissions should be calculated according to [Formula 9](#):

$$E_{\text{net energy supply, market}} = (J_{\text{total supplied}} - J_C) \times f_{\text{energy supplied}} + J_C \times f_C \quad (9)$$

where

$E_{\text{net energy supply, market}}$	is the GWP-weighted emissions, associated with supply of energy (i) within the module measured in kilograms of CO ₂ e using Equation 1 (calculated in line with the market-based electricity approach);
$J_{\text{total supplied}}$	Total supplied energy
$f_{\text{energy supplied}}$	Emission factor for the supply of energy not associated with certificates
J_C	Supply of energy for which relevant certificates have been purchased
f_C	Emission factor for the supply of energy for which relevant certificates have been purchased

4.3.2.5.2 Treatment of electricity

GHG emissions from electricity used for hydrogen production shall be restricted to direct emissions and indirect emissions (not including capital goods emissions). Emissions shall include extraction and transport of primary energy commodities used to generate electricity, transformation (i.e. electricity generation), and transmission and distribution losses.

The direct GHG emissions of electricity generation from wind, solar photovoltaic, hydropower, may be assumed to be zero. As mentioned in [4.2.1](#), capital goods emission shall be reported for information.

The GHG emissions associated with the use of electricity shall include GHG emissions arising from the supply of the electricity including:

- the supplied electricity counted at the in gate of the hydrogen-production facility;
- the losses from the electricity generation process and from transmission and distribution.

a) Electricity generation within the boundaries of the hydrogen production facility

When electricity is generated within the facility and consumed to produce hydrogen and no contractual instruments have been sold or brought through a third-party, then the emissions would be any direct and indirect emissions, as applicable, resulting from generating that electricity. Emissions associated with on-site generation shall not be double counted if already included in the process emissions ([Section 4.3.2.2](#)).

b) Electricity generation outside the boundaries of the hydrogen production facility

Electricity supplied to the facility shall account for emissions associated with electricity generation, transmission, and distribution consumed by the plant, considering upstream emissions, operational and downstream emissions and all losses in the electricity-generation facility and transmission and distribution losses. If the GHG evaluation goal is attributional (see [4.1.2](#)):

The electricity emissions reporting method proposed is consistent with ISO 14064-1:2018, Annex E. This approach includes dual reporting requirements consisting of a location-based and market-based method.

The following is adapted from ISO 14064-1:2018, Annex E.

Provided that market based contractual instrument and default emission factors (residual mix) meet proper quality criteria (see [Section 4.3.1](#)), the market-based method should be used whenever possible in priority to determine the emission factor of electricity used to produce hydrogen. An example of quality criteria for market-based information can be found in the ISO 14064-1:2018, Annex E.

If the GHG evaluation goal is consequential (see [4.1.3](#)):

The system boundary is usually defined by the goal of the LCA. Regardless of whether electricity is purchased on the generic electricity market or from a specific supplier, a consequential approach may consider effects that are expected as a consequence of changes in electricity demand. Consequential approaches for treatment of electricity are of particular relevance for policy making, where there is an interest in the direct and indirect impacts of expanding hydrogen production and an aim to reduce negative (unintended) effects (see [Annex B](#) – Consequential Approach Examples for Hydrogen Production, which includes examples of regulations using a consequential approach for estimating GHG emissions associated with electricity).

4.3.2.5.3 Treatment of steam

The steam involved in different processes can be (1) a heat input (e.g. to ensure the required temperature within different sub-processes), (2) a feedstock (e.g. high temperature electrolysis or gas reforming), or (3) a co-product (e.g. steam co-produced in SMRs).

When steam is an input to the hydrogen production facility, the emissions assigned to its production and supply shall be allocated to the co-products of the hydrogen production facility, including the hydrogen, as described in [4.3.3](#) and the relevant annexes for emissions allocations.

Carbon footprint of the steam supplied to the hydrogen production facility shall be estimated according to ISO 14067.

When steam is a co-product, the GHG emissions shall be determined and allocated based on the process outlined in [Section 4.3.3](#).

4.3.2.5.4 Treatment of natural gas

Depending on the available data, calculating the emissions factor for the natural gas used, whether as an energy input or feedstock (kgCO₂e / MJ), shall be done according to the following priority order:

1. using an emission factor derived from direct measurements, where applicable and practical, at the source and site-level⁴⁾ of the gas purchased that is verified by an independent, third-party verifier (see [3.5.5](#) site-specific data); or if not available
2. using a well-documented and, where available basin-specific, emission factor of the regional gas industry based on an independent, third-party, public-funded scientific analysis (for example the analysis aggregated and validated through the UN Environment Programme's International Methane Emissions Observatory (IMEO)⁵⁾); or if not available
3. using an emission factor (the system boundary of the data should match that of the gas purchased) provided by a national authority, or data source which is generally used in the country or area where the natural gas production is located, or otherwise globally used LCA data base. The database name and version shall be reported.

The aforementioned emission factor shall include GHG emissions from gas transport to the hydrogen production facility and fugitive emissions. The emission factor for natural gas shall be reported and justified.

4) Oil and Gas Methane Partnership (OGMP) 2.0 framework <https://ogmpartnership.com/>

5) <https://www.unep.org/topics/energy/methane/international-methane-emissions-observatory>

For references on calculating GHG emissions at LNG plants and throughout the LNG chain, refer to ISO6338:2023 and ISO/DIS 6338-2.

Treatment of other possible sources of methane, such as biogas, is provided in [Annex C](#) on feedstocks.

4.3.2.6 Upstream Emissions

Upstream emissions (excluding emissions associated from energy supply, [Section 4.3.2.5](#)) refer to upstream emissions associated with any input to a system. This can include key inputs such as oxygen gas among others. Additional input streams may be considered on an as required, based on the cut-off criteria per [4.2.1](#). This can include items such as water used for electrolysis and chemicals used for water treatment.

All GHG emissions associated with water supply for the production of hydrogen shall be captured within the CFP.⁶⁾

The overall calculation for estimation of upstream emissions is as follows:

$$E_{\text{upstream emissions}} = \sum_i E_{\text{upstream emissions},i} \quad (11)$$

where $E_{\text{upstream emissions}}$ is the GWP-weighted, associated with input (i) measured in kilograms of CO₂e according to [Equation 1](#).

[Annex C](#) provides additional guidance regarding the estimation of carbon footprints of feedstocks to hydrogen production plants.

4.3.3 Emissions allocation

Production pathways for hydrogen often result in various wastes, products and co-products.

According to ISO 14067: 2018, 6.4.6.1: the inputs and outputs shall be allocated to every products and co-products according to a clearly stated and justified allocation procedure.

According to ISO 14067:2018, 6.4.6.2: *“The CFP study shall include the identification of the processes shared with other product systems and deal with them in accordance with the stepwise procedure presented below.*

NOTE *Formally, step 1 is not part of the allocation procedure.*

- a) **Step 1:** *Wherever possible, allocation should be avoided by*
 - 1) *dividing the unit process to be allocated into two or more sub-processes separately and collecting the input and output data related to these sub-processes, or*
 - 2) *expanding the product system to include the additional functions related to the co-products.*
- b) **Step 2:** *Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them.*
- c) **Step 3:** *Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and the functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.”*

In this document the steps of the allocation procedure according to ISO 14067 are differentiated between an attributional and a consequential approach ([Table 3](#)).

The specific allocation method depends on the production process and the associated co-products. Refer to the [annexes D](#) to [L](#) for more detailed guidance on allocation methods.

6) Where water supply has been treated/processed, upstream emissions with that activity should be considered in building the emissions inventory

Table 3 — Allocation procedure for co-products of the hydrogen production pathway according to ISO 14067:20183, 6.4.6.2 as applied in this document for attributional and consequential approach

Allocation procedure according to ISO 14067:2018, 6.4.6.2	Application in ISO 19870	
	Attributional approach	Consequential approach
Step 1: Wherever possible, allocation should be avoided by		
(1) dividing the unit process to be allocated into two or more sub-processes separately and collecting the input and output data related to these sub-processes, or	Applicable	Applicable
(2) expanding the product system to include the additional functions related to the co-products.	Not applicable as: (1) changing the functional unit to include hydrogen and other co-products is not aligned with this document, which defines the functional unit as 1 kg of hydrogen, and (2) system expansion via substitution is consequential by definition	Applicable for system expansion via substitution Not applicable for system expansion via changing the functional unit to include hydrogen and other co-products is not aligned with this document, which defines the functional unit as 1 kg of hydrogen
Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them.	Applicable	Not applicable as this step does not evaluate consequences of co-production
Step 3: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and the functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.	Applicable	Not applicable as this step does not evaluate consequences of co-production

This document applies the allocation procedure according to ISO 14067:2018, 6.4.6.2 as follows ([Table 3](#)):

Step 1.1: Dividing the unit process to be allocated into two or more sub-processes separately and collecting the input and output data related to these sub-processes

Step 1.1 applies to an attributional and a consequential approach. The following steps help determine whether or not multi-functionality is solvable by subdivision:

- (1) Investigate whether the analysed unit process contains physically distinguishable sub-processes,
- (2) Investigate whether or not it is possible to collect or determine data exclusively for those sub-processes,
- (3) Check whether separate sub-processes can be identified and modelled –each only providing one required functional output.

Based on the outcome, one of the following three options should apply:

- (1) Subdivision should be performed, if it is possible to collect or determine data exclusively for those sub-processes.

For example, as described in [Annex D](#), a steam reformer co-producing carbon monoxide (CO), hydrogen, and steam may be virtually subdivided as:

- The SMR reactor producing syngas and steam;

- The CO cold box producing CO and hydrogen and having syngas as an input;
 - The water gas shift producing hydrogen and having syngas as an input.
- (2) Virtual subdivision should be attempted when a process has 2 or more different inputs with the same physical and chemical characteristics coming from different upstream processes and therefore with different carbon footprints. The process may be virtually subdivided to be considered as the juxtaposition of 2 or more separate processes, each representing one of the different inputs of the subdivided process.
- For example,
- A PSA purifying two similar hydrogen rich streams may be virtually subdivided in two parts, each of them considered as a separate PSA treating one of the two flows
 - An electrolyser partially consuming renewable electricity may be virtually subdivided in two sub-process and considered as the juxtaposition of one electrolyser consuming exclusively the renewable electricity and another one consuming the remaining part.
- (3) Neither subdivision nor virtual subdivision can be performed.

Step 1.2: Expanding the product system to include the additional functions related to the co-products

Expanding the product system to include the additional functions related to the co-products only applies to a consequential approach. It is not applicable to an attributional approach. There are two possibilities for how to apply system expansion:

- (1) Via changing the functional unit to include hydrogen and other co-products, and
- (2) Via substitution by assigning a co-product the same carbon footprint as an alternative product.

System expansion via changing the functional unit to include hydrogen and other co-products is not aligned with this document, which defines the functional unit as 1 kg of hydrogen (See [4.2.1.1](#) General principles).

System expansion via substitution is only applicable for a consequential approach, as the consideration of (hypothetical) alternatives is by definition consequential (See [4.1.3](#) Consequential approach). Substitution considers alternative production pathways of a co-product. The partial CFP associated with the substituted product(s) is subtracted from the product system under study (see [Figure 4](#)).

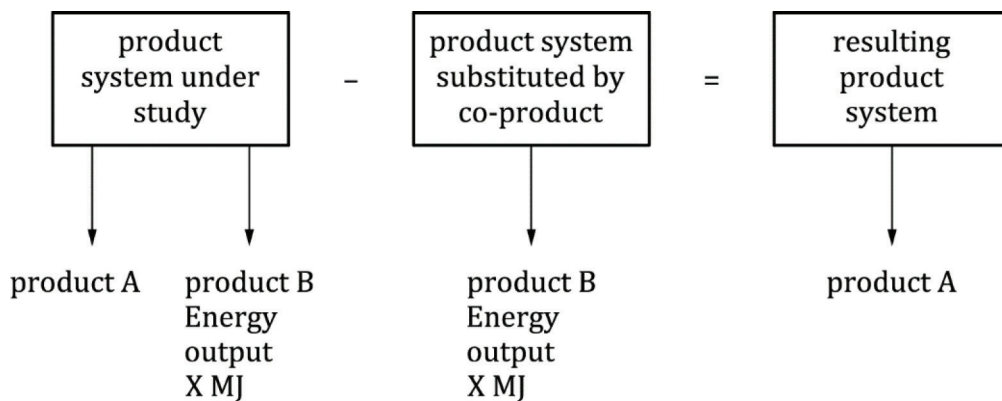


Figure 4 — Example of avoiding allocation by using system expansion via substitution (ISO 14044:2006 / AMD 2:2020).

Note In this particular example, product B is an energy product, but could be any product.

The application of system expansion involves an understanding of the market for the co-products. Decisions about system expansion can be improved through understanding the way co-products compete with other products, as well as the effects of any product substitution upon production practices in the industries impacted by the co-products.

Important considerations relating to the identification of relevant substitution pathways include:

- Whether specific markets and technologies are affected;
- Whether the production volume of the studied product systems fluctuates over time;
- Whether a specific unit process is affected directly;
- If inputs are delivered through a market, it is also important to consider:
 - whether any of the processes or technologies supplying the market are constrained, in which case their output does not change in spite of changes in demand;
 - which of the unconstrained suppliers/technologies has the highest or lowest production costs and, therefore, is the supplier/technology affected when the demand for the supplementary product is generally decreasing or increasing, respectively.

The justification of the choice of system expansion can be based on technical considerations. System expansion via substitution can be a straightforward choice for energy products. But where there are multiple industrial pathways for co-products, the model results can have high variability. If there are different possibilities of substitution of a co-product, this can lead to significantly different results. Therefore, the substitute systems for each co-product should be defined and justified.

Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them

Allocation of GHG emissions between different co-products in a way that reflects the underlying physical relationships between them is only applicable in an attributional approach. It is not applicable following a consequential approach, as this procedure does not evaluate any consequences of or alternative means to co-production.

Physical relationship: in many cases the input flows can be allocated to co-products based on the specific function they perform in relation to the individual co-products and/or the direct GHG emissions can be allocated to co-products based on an underlying relationship between the co-products and their emissions contribution. Possible physical parameters or combinations of some of them for allocation include energy content, mass, and mole.

The parameter selected for the allocation method should be consistent with the purpose of the hydrogen production facility and should reflect the reason why inputs are used and GHG are emitted.

It should be noted that considerable differences in allocation results may occur. For example, electricity used for water electrolysis coproduces hydrogen and oxygen. In case of oxygen valorization, a mass-based allocation will allocate 16 times more GHG emissions to oxygen than to hydrogen, while a mole-based allocation will allocate only half as many GHG emissions to oxygen as to hydrogen.

Step 3: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and the functions in a way that reflects other relationships between them.

Allocation of GHG emissions between different co-products in a way that reflects a relationship other than a physical relationship is only applicable in an attributional approach. It is not applicable following a consequential approach, as this procedure does not evaluate any consequences of or alternative means to co-production.

An example for an allocation method relying on a relationship other than a physical relationship is to allocate GHG emissions between co-products in proportion to the economic value of the co-products.

Such an allocation based on economic value may reflect the intention of operating a process. The relative revenues may impact choices in production, specifically whether to favor or produce more of one co-product over another. Economic allocation may help to reflect differences between regions and markets for similar products. Economic allocation has the potential to differentiate between similar products having different

quality attributes. Economic allocation for hydrogen production specifically is complicated more in markets where the price of hydrogen depends on the CFP of hydrogen, therefore creating a circular argument which may make economic allocation impossible.

However, it should also be noted that market prices may vary over time, and between different regions and market actors. The selection of the allocation factors represents a value choice and the allocation factor may show a high uncertainty, especially for future scenarios. The application of allocation based on economic value depends on having market prices for all co-products. Furthermore, allocating based on cost- or revenue might not reflect the physical causalities of producing or purchasing a specific product. Therefore, economic allocation may only be used when a relevant physical relationship cannot be established.

The economic value shall be considered at the point (i.e. at plant/service provider), in the condition (e.g. not purified/technical quality), and in the amount (e.g. bulk) that co-products are provided by the multifunctional process. The specific market price shall be used as the economic value. If the co-products are not traded at that point of allocation and with their specific characteristics, the market price has to be derived by combining production cost information and the market price of the further processed, packed, transported co-product.

Any additional steps of transport, conditioning, packaging etc. are to be considered to make sure the economic value used for allocation reflects the value of each co-product at the point where and in the condition in which it is delivered.

4.4 CFP study report

After completing the CFP study of hydrogen, the applicant should prepare a CFP study report (per ISO 14067). Useful guidance can be found in GHG Protocol^{[9][10][11]}. Critical review

5 Critical review

In compiling the CFP study, a critical review facilitates understanding and enhances the credibility of CFP. A critical review of CFP studies, if any, shall be performed in accordance with ISO/TS 14071.

Annex A (Normative)

Hydrogen Purity

A.1 Background

In practice, hydrogen production facilities are likely to produce gas streams that are not 100 % hydrogen because they contain traces of impurities (i.e., gases that are not hydrogen). A high purity hydrogen can be practically pure if impurities have negligible impact on the greenhouse gases (GHG) emissions calculation of hydrogen. A purity level of 99,9 % mole fraction of hydrogen (0,1 mole% impurities), for example 0,1 mole% of CO₂ impurity, may add 0,022 kgCO₂e/kg hydrogen (or < 0,2 gCO₂e/MJ hydrogen) and increase the emission for 1 kg of pure H₂ (@100 %).

For most hydrogen applications, the purity level requirement exceeds 99,9 %. The following are examples of the gaseous hydrogen (Type I) fuel quality specification in the ISO 14687:2019 for various stationery and vehicle applications with purity specification ≥ 99 %: grade B (99,9 % purity); grade E, category 3 (99,9 % purity); grade C (99,995 % purity); and grade D (99,97 % purity). Grade A and F have purity specification ≥ 98 %.

For hydrogen purity below 99,9 % mole fraction, the purity of hydrogen becomes significant for calculating GHG emissions of hydrogen considering two important factors:

- (1) the amount of impurities (e.g., x% by mole) impacts the life cycle functional unit of hydrogen, typically a mass unit of 1 kg, especially when considering the much smaller molecular weight of hydrogen compared to most impurities (e.g., N₂, CO, CO₂, etc.) For example, 1 % of CO₂ impurity (mole basis, i.e., 99 % hydrogen purity) in 1 kg of the gas product represents 18 % of CO₂ by mass, thus only 0,82 kg is the share of H₂ in the 1 kg of gas product. This is in contrast with the assumed 1 kg of hydrogen product if the CO₂ impurity is ignored based on its small share on per mole basis.
- (2) If the impurity contains non-biogenic carbon in its chemical composition (e.g., CO, CO₂, CH₄), such impurities can add to the GHG emissions of hydrogen assuming oxidation of the carbon containing impurity to CO₂ before being emitting to atmosphere. Considering the previous example, each 1 % (by mole) of non-biogenic CO and CO₂, and of CH₄ in the product gas will add 0,22 kg of CO₂ per kg of molecular H₂ to the GHG emissions of hydrogen assuming the oxidation of these carbon containing impurities before emitting to the atmosphere, whereas, if the produced hydrogen gas is not combusted, emissions of 1 % of biogenic or non-biogenic CH₄ (by mole) will increase the GHG emissions of hydrogen gas by the CH₄ equivalent CO₂ (i.e., by considering the global warming potential of biogenic and non-biogenic CH₄ according to IPCC). Thus, it is important to account for the fate of the non-biogenic carbon in the impurities, as well as the fate of the CH₄ impurity, and quantify their potential impact on the GHG emissions calculations of hydrogen product (kgCO₂e/kg hydrogen). The methodology described below provides details on how the GHG emissions of hydrogen in kgCO₂e/kg hydrogen can be calculated, considering the two factors mentioned above.

A.2 Method [Normative]

The following example describes how to account for impact of carbon containing and non-carbon impurities on the GHG emissions calculation of hydrogen product. In this example,

- y (kg CO₂e/kg hydrogen gas) is the sum of “raw material extraction to production gate” GHG emissions (direct and indirect) associated with the production of hydrogen gas leaving the hydrogen plant before accounting for carbon in impurities

- x_{H_2} (mol H_2 /mol gas) is the mole fraction of hydrogen in the hydrogen gas product (including impurities) leaving the hydrogen plant
- x_{CH_4} (mol CH_4 /mol gas) is the mole fraction of methane in the hydrogen gas product (including impurities) leaving the hydrogen plant
- x_{CO} (mol CO /mol gas) is the mole fraction of non-biogenic carbon monoxide in the hydrogen gas product (including impurities) leaving the hydrogen plant
- x_{CO_2} (mol CO_2 /mol gas) is the mole fraction of non-biogenic carbon dioxide in the hydrogen gas product (including impurities) leaving the hydrogen plant
- x_{N_2} (mol N_2 /mol gas) is the mole fraction of nitrogen in the hydrogen gas product (including impurities) leaving the hydrogen plant
- x_{H_2O} (mol H_2O /mol gas) is the mole fraction of water in the hydrogen gas product (including impurities) leaving the hydrogen plant
- x_i (mol of species (i)/mol of hydrogen gas) is the mole fraction of product (including impurities) leaving the hydrogen plant
- MW_{H_2} (g H_2 /mol H_2) is the molecular weight of H_2
- MW_{CH_4} (g CH_4 /mol CH_4) is the molecular weight of
- MW_{CO} (g CO /mol CO) is the molecular weight of carbon monoxide
- MW_{CO_2} (g CO_2 /mol CO_2) is the molecular weight of carbon dioxide
- MW_{N_2} (g N_2 /mol N_2) is the molecular weight of nitrogen
- MW_{H_2O} (g H_2O /mol H_2O) is the molecular weight of water
- MW_{gas} (g gas/mol gas) is the molecular weight of gas
- MW_i (g species i/mol species i) is the molecular weight of species i

If the non-biogenic carbon content impurities and CH_4 in the hydrogen gas product are assumed to be completely oxidized (e.g., combusted), then the mass of CO_2 emitted from these impurities per unit mass of molecular H_2 will be calculated according to [Equation A.1](#):

$$c = \frac{(x_{CH_4} + x_{CO} + x_{CO_2}) MW_{CO_2}}{x_{H_2} MW_{H_2}} \left(\frac{kg CO_2}{kg H_2} \right) \quad (A.1)$$

If the produced hydrogen gas is not completely oxidized, in this case, assuming that methane is not oxidized and is released to the atmosphere, but that CO is completely oxidized, the emissions of biogenic or non-biogenic CH_4 will be accounted for according to the IPCC global warming potential (GWP) of biogenic and non-biogenic CH_4 . In this case, the GHG emissions from these impurities in mass unit of CO_{2e} per unit mass of molecular H_2 will be calculated according to [Equation A.2](#):

$$c = \frac{x_{CH_4} \times MW_{CH_4} \times GWP_{CH_4} + (x_{CO} + x_{CO_2}) \times MW_{CO_2}}{x_{H_2} MW_{H_2}} \left(\frac{kg CO_{2e}}{kg H_2} \right) \quad (A.2)$$

Considering the unit mass of hydrogen gas product (instead of unit mass of molecular H_2) as the functional unit, the mass of CO_2 emitted upon complete oxidation or combustion of hydrogen gas product (including impurities) can be calculated according to [Equation A.3](#):

$$c' = \frac{(x_{CH_4} + x_{CO} + x_{CO_2}) MW_{CO_2}}{MW_{gas}} \left(\frac{kg CO_2}{kg \text{ hydrogen gas produced, including impurities}} \right) \quad (A.3)$$

or, if CH₄ is emitted instead of combusted, c' will be calculated according to [Equation A.4](#):

$$c' = \frac{x_{CH_4} \times MW_{CH_4} \times GWP_{CH_4} + (x_{CO} + x_{CO_2}) MW_{CO_2}}{MW_{gas}} \left(\frac{kg CO_{2e}}{kg \text{ hydrogen gas produced, including impurities}} \right) \quad (A.4)$$

Where MW_{gas} in this case is given in [Equation A.5](#).

$$MW_{gas} = x_{CH_4} MW_{CH_4} + x_{CO} MW_{CO} + x_{CO_2} MW_{CO_2} + x_{H_2} MW_{H_2} + x_{H_2O} MW_{H_2O} + x_{N_2} MW_{N_2} \quad (A.5)$$

The GHG emissions of the gas product (excluding impurities) leaving the hydrogen plant in units of (kg CO_{2e} / kg hydrogen gas produced, including impurities) can be calculated according to [Equation A.6](#):

$$y + c' \left(\frac{kg CO_{2e}}{kg \text{ hydrogen gas produced, including impurities}} \right) \quad (A.6)$$

The GHG emissions of the molecular hydrogen component (H₂) of the gas product (excluding impurities) leaving the hydrogen plant in units of (kg CO_{2e} / kg hydrogen) can be calculated according to [Equation A.7](#):

$$(y + c') \cdot \left[\frac{MW_{gas}}{x_{H_2} MW_{H_2}} \right] \left(\frac{kg CO_{2e}}{kg H_2} \right) \quad (A.7)$$

These emission factors shall be calculated by the hydrogen gas producer and provided to recipients of hydrogen gas (including quantitative description of impurities) for potential use in the life cycle assessments of products manufactured from hydrogen gas, including its end use.

If the hydrogen gas (including impurities) is employed by its recipient as a fuel (i.e., completely combusted), then the life cycle GHG emissions per unit of the combusted hydrogen gas fuel (including impurities) at end use application, assuming no mass losses in the hydrogen gas transport, can be calculated according to [Equation A.8](#):

$$y + c' \left(\frac{kg CO_{2e}}{kg \text{ hydrogen gas produced, including impurities}} \right) \quad (A.8)$$

or the life cycle GHG emissions per mass unit of the molecular hydrogen product can be calculated according to [Equation A.9](#):

$$(y + c') \cdot \left[\frac{MW_{gas}}{x_{H_2} MW_{H_2}} \right] \left(\frac{kg CO_{2e}}{kg H_2} \right) \quad (A.9)$$

The preceding formulas require that the hydrogen production facility measures the mass flow rate of the (H₂ + impurities) gas product and the chemical composition (mol%) of each impurity in the hydrogen product gas, including that of hydrogen (mol%) (e.g., via gas analyzer).

In the attributional approach, the CFP of the hydrogen gas (including impurities) at the hydrogen production facility is y , as previously described, and the fate of remaining (non-biogenic) carbon in the impurities shall be accounted for in the downstream use of hydrogen gas (including impurities) according to [equations A.7](#) and [A.8](#).

In a consequential approach that accounts for the fate of carbon in impurities at end use application of hydrogen gas (including impurities), c' shall be included in the CFP of hydrogen according to [equations A.5](#) and [A.6](#) if the fate of non-biogenic carbon in the impurities is known or assumed to be CO₂ in the atmosphere, except for CH₄ when the hydrogen gas is not used as fuel, in this case the CH₄ greenhouse effect should be

accounted for with its global warming potential (GWP) according to IPCC. If the hydrogen gas (including impurities) is ultimately used in a process that captures and sequesters the carbon in the impurities (i.e., does not release it as GHG to the atmosphere), then including c' in the partial CFP of hydrogen gas (including impurities) is inappropriate.