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Global programme for hydrogen in industry

Guide on ISO/TS 19870

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Contents

List of acronyms, abbreviations and units

CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CFP	Carbon Footprint of a Product
CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
GHG	Greenhouse Gases
GTP	Global Temperature Potential
GWP	Global Warming Potential
GWP100	Global Warming Potential over 100 Years
IEA	International Energy Agency
ILCD	International Reference Life Cycle Data System
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IPPC AR5	Intergovernmental Panel on Climate Change Fifth Assessment Report
ISO	International Organization for Standardization
kg	Kilogram
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
N_2O	Nitrous Oxide
Q&A	Question and Answer
SDGs	Sustainable Development Goals
TC 197/SC 1/WG 1	Technical committee 197/subcommittee 1/working group 1
TS	Technical Specification
UNIDO	United Nations Industrial Development Organization

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Disclaimer

About ISO

ISO (International Organization for Standardization) is a global network that identifies which International Standards are required by business, government and society, develops them in partnership with the sectors that will put them to use, adopts them by transparent procedures based on national, multi-stakeholder input, and delivers them to be implemented worldwide.

ISO standards distil an international consensus from the broadest possible stakeholder bases. Expert input comes from those closest to where the standards are needed and is informed by lessons learned from implementing the standards. For this reason, although voluntary, ISO standards are widely respected and accepted by public and private sectors internationally.

As a non-governmental organization, ISO is a federation of national standards bodies from all regions of the world – one for each country – including developed and developing countries and countries with economies in transition. Each ISO member is the principal standards organization in its country. Members propose ideas for new standards, take part in their development under the coordination of the ISO Central Secretariat, and provide support to more than 3 500 technical groups that develop the standards.

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About UNIDO

The mission of the United Nations Industrial Development Organization (UNIDO) is to promote and accelerate inclusive and sustainable industrial development (ISID) in member states.

The relevance of ISID as an integrated approach to all three pillars of sustainable development is recognized by the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs), which will frame the United Nations' and countries' efforts towards sustainable development until 2030. UNIDO's mandate is fully recognized in SDG 9, which calls to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation". The relevance of ISID, however, applies in greater or lesser extent to all SDGs.

Accordingly, the organization's programmatic focus is structured in four strategic priorities: 1) creating shared prosperity, 2) advancing economic competitiveness, 3) safeguarding the environment and 4) strengthening knowledge and institutions. Each of these programmatic fields of activity contains a number of individual programmes, which are implemented in a holistic manner to achieve effective outcomes and impacts through UNIDO's four enabling functions: (i) technical cooperation; (ii) analytical and research functions and policy advisory services; (iii) normative functions and standards and quality-related activities; and (iv) convening and partnerships for knowledge transfer, networking and industrial cooperation.

In carrying out the core requirements of its mission, UNIDO has considerably increased its technical services over the past ten years. At the same time, it has also substantially increased its mobilization of financial resources, testifying to the organization's growing international recognition as an effective provider of catalytic industrial development services.

UNIDO has 170 Member States. It is headquartered in Vienna, Austria, but operates worldwide. Established in 1966, it became a specialized agency of the United Nations in 1985.

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1. Foreword

International Organization for Standardization (ISO) is an independent, non-governmental organization that, through its membership of 172 national standards bodies, brings together experts to share knowledge and develop voluntary, consensus-based, market-relevant international standards that support innovation and provide solutions to global challenges. ISO has covered hydrogen technologies through its technical committee 197 (ISO/TC 197) since 1990. Other technical committees, such as ISO/TC 58, *Gas cylinders*, also develop standards relevant to the hydrogen field.

United Nations Industrial Development Organization (UNIDO) is the specialized agency of the United Nations that promotes industrial development for poverty reduction, inclusive globalization, and environmental sustainability. UNIDO assists developing and transition economies with their industrialization processes, providing technical assistance, policy advice, and capacity-building programmes. Its aim is to enhance the competitiveness of industries, promote trade and investment, and foster sustainable industrial growth that contributes to economic development and the achievement of the Sustainable Development Goals (SDGs).

The synergies between UNIDO's and ISO's goals have led to a partnership spanning more than 40 years. Since the outset, UNIDO has served on technical committees, providing technical input during the standards development process. UNIDO and ISO work to enable developing and transition economies to take a more active role in the development and adoption of International Standards, as well as to help their enterprises and institutions apply and comply with International Standards and conformity assessment guidelines.

UNIDO's Global Programme for Hydrogen in Industry addresses activities to accelerate the uptake of low-emission hydrogen for industrial application in developing and transition economies. It aims to serve as a global platform to raise awareness among stakeholders participating in the low-emission hydrogen ecosystem, exchange of experiences, capacity building, development of knowledge materials, policy dialogue and joint development of country-specific low-emission hydrogen projects in industry. UNIDO liaises with ISO's TC 197/SC 1, *Hydrogen at scale and horizontal energy systems*, and has actively participated in the activities of this subcommittee.

UNIDO, in partnership with ISO, and supported by the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), the Hydrogen Council, and Hydrogen Europe, have collaborated to develop this guide to ISO/TS 19870, *Hydrogen Technologies – Methodology for determining the greenhouse gas emissions associated with the production, conditioning and transport of hydrogen to consumption gate*. This guide aims to make the ISO/TS 19870 standard more accessible to practitioners, industry professionals, and government stakeholders. It is not meant to be a standalone document. Instead, it is intended to support ISO/TS 19870 by explaining and streamlining the methodology, enhancing its visibility, and promoting its recognition. The best way to use this guide is to be familiar with ISO/TS 19870 and then follow each section in the order provided. The guide will refer to ISO Life Cycle Assessment (LCA) and Carbon Footprint of a Product (CFP) phases and the original ISO/TS 19870 sections, while providing relevant context and explanation. Throughout the guide, Q&A boxes are displayed, answering the most-commonly asked questions regarding each specific section.

What is ISO/TS 19870?

ISO/TS 19870 is a technical specification offering a methodology for determining the greenhouse gas (GHG) emissions associated with the production, conditioning, and transport of hydrogen up to consumption gate. It provides a comprehensive framework for assessing the partial carbon footprint of hydrogen technologies, from well to consumption gate, covering all life cycle stages of hydrogen.

Why is ISO/TS 19870 important?

Countries have been introducing national legislation for hydrogen, making different policy choices with respect to the types of hydrogen that they intend to deploy and support, in particular based on different GHG emissions intensity thresholds. ISO/TS 19870 is critical for standardizing GHG emissions assessment throughout various hydrogen production and delivery pathways. It supports global climate goals by offering a transparent, consistent benchmark for evaluating and comparing hydrogen's environmental impact. This is essential for fostering trust among investors and aiding in hydrogen certification.

Who should use ISO/TS 19870?

Stakeholders in the hydrogen value chain, such as hydrogen production, conditioning, conversion, and transport, including technicians, entrepreneurs, policymakers, investors, and certification bodies.

2. Background

What is the International Organization for Standardization (ISO)? How does it work and how can I join?

ISO is a global Standard Development Organization with a 75-year history in the field of international standardization focused on developing, publishing, or disseminating technical standards to meet the needs of a given field. To join an ISO work group, those interested typically start by identifying and contacting their national standards body to express an interest. Membership often requires demonstrating expertize in the relevant field and being part of the national standards body or a related technical committee. Once involved, those interested can participate in meetings, contribute to the development of standards, and engage with other experts to work on the creation and revision of international standards. ISO encourages the participation of a diverse range of experts and stakeholders in the development of standards. ISO's consensus-based approach relies on the input and collaboration of these varied participants to ensure that the standards are comprehensive, balanced, and applicable globally.

What is UNIDO?

UNIDO is a specialized agency of the United Nations with a unique mandate to promote, dynamize and accelerate industrial development. Its mandate is reflected in Sustainable Development Goal (SDG) 9: "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation," but UNIDO's activities contribute to all the SDGs.

UNIDO's vision is a world without poverty and hunger, where industry drives low-emission economies, improves living standards, and preserves the livable environment for present and future generations, leaving no one behind. UNIDO provides support to its 172 Member States through four mandated functions: technical cooperation; action-oriented research and policy-advisory services; normative standards-related activities; and fostering partnerships for knowledge and technology transfer.

What is the main technical committee leading the work on hydrogen within ISO?

ISO/TC 197, *Hydrogen technologies* leads standardization in the field of systems and devices for the production, storage, transport, measurement, and use of hydrogen. ISO/TC 197, *Hydrogen at scale and horizontal energy systems*, subcommittee 1, focuses on the standardization of large-scale hydrogen energy systems and applications, in particular related to aspects of sustainability, testing, certification and placement, and coordination with relevant standardization bodies and stakeholders.

In 2019, during the 32nd IPHE Steering Committee, participating countries recognized that establishing harmonized international accounting standards encompassing different hydrogen processes along the supply chain was crucial to creating a unified market for low-emission hydrogen. To address this issue, IPHE created the Hydrogen Production Analysis Task Force to propose a methodology and analytical framework for determining the GHG emissions related to a unit of produced hydrogen, potentially serving as the basis for an international certification scheme. As a result, in 2021, the first version of the "Methodology for determining the greenhouse gas emissions associated with the production of hydrogen" was released. This methodology is based on the principles of inclusiveness, not excluding any potential primary energy sources or technologies; flexibility, allowing for unique circumstances and adapting to the context in which it is applied; transparency, building confidence through clear assumptions and reporting; comparability, enabling 'apples to apples' emissions comparisons through different pathways and energy sources; and practicality, ensuring the methodology is practical for industry adoption and market use. After publication, IPHE handed over the methodology to ISO to be transformed into an International Standard.

Considering the role of hydrogen in the energy transition and ISO commitment to support international development, it was a natural step for ISO/TC 197, via its subcommittee 1, to take on the development of an ISO Methodology for GHG emissions assessment of hydrogen. In 2023, ISO published the ISO technical specification (ISO/TS) 19870, *Hydrogen technologies — Methodology for determining the greenhouse gas emissions associated with the production, conditioning and transport of hydrogen to consumption gate*. This methodology represents a pivotal step to foster the growth of the hydrogen market by providing a unified, transparent tool to assess the GHG emissions in the hydrogen value chain. ISO/TS 19870 was prepared by technical committee ISO/TC 197, *Hydrogen technologies*, SC 1, *Hydrogen at scale and horizontal energy systems*, with support from many different stakeholders, such as IPHE, UNIDO, Hydrogen Council and Hydrogen Europe. The methodology provides a framework for assessing the GHG footprint of hydrogen as a product from resource extraction to consumption gate (well to consumption gate), including every delivery gate on a life cycle analysis basis. It was launched on 5 December 2023 as one of the Lead Outcomes on the Presidential Action Agenda for Hydrogen at COP28 at the High-Level Roundtable on Hydrogen. ISO/TS 19870 is the first in a series of ISO standards for assessing the GHG emissions in the hydrogen value chain.

What are the main benefits of standardizing GHG emissions assessment with ISO/TS 19870?

ISO/TS 19870 provides a standardized framework for GHG emissions assessment in hydrogen technologies. Thereby it:

- enhances transparency and comparability in the hydrogen market,
- supports informed decision-making and policy formulation on hydrogen deployment,
- facilitates the certification and sustainability assessment of hydrogen,
- contributes to global efforts by understanding the potential role of hydrogen to mitigate climate change.

What is the role of ISO's methodology for GHG emissions assessment of hydrogen for global investors?

ISO's methodology will play a critical role in helping build trust in the sustainability of hydrogen as a new globally traded commodity to:

- foster transparency at a global level for investors and end users,
- help build consumer trust and support bankable offtake,
- advance competition between different hydrogen pathways based on their GHG footprint,
- provide a common global benchmark methodology for all low-emission hydrogen pathways, acting as an enabling tool to implement sovereign policy choices of countries at national level.

This methodology should be used to compare the emissions in the hydrogen value chain from different pathways in a quantitative, transparent, and comprehensive way. This methodology does not replace national requirements or methodologies that may be set by law by sovereign nations. ISO International Standards are voluntary and do not replace national laws, with which standards users are understood to comply and that take precedence. Moreover, national laws may refer to ISO standards.

3. Introduction

The uncontrolled emission of greenhouse gases is one of the main challenges of the 21st century. There is a direct correlation between the CO_2 and other greenhouse gases concentrations in the atmosphere and the mean global temperature, which has been rising rapidly since the onset of the Anthropocene, due to human demand for energy.

Despite efforts to mitigate this trend, global energy demand is expected to grow alongside increases in global population and urbanization rates. Developed economies continue to have high energy demands to sustain their industrial activities and lifestyles. Meanwhile, developing and transition economies are rapidly industrializing, further driving up global energy consumption and contributing to greenhouse gas emissions. To tackle this challenge from both supply and demand sides, hydrogen represents a crucial opportunity.

Climate change is no longer a future threat; its effects are already being felt through extreme weather events, heatwaves, flooding, rising sea levels, and coastal erosion, impacting the daily lives of millions worldwide. The continued rise in global temperatures is projected to magnify these effects, leading to adverse environmental, societal, and economic consequences.

To coordinate global efforts to mitigate climate change, achieve Net-Zero, and meet the goals of the Paris Agreement by 2050, it is crucial to decarbonize existing energy systems and industries by adopting technologies that are lower in emissions and more energy-efficient.

In 2022, the world produced and consumed 95 million tonnes of hydrogen,[1] but nearly all hydrogen was produced without carbon abatement. Hydrogen has the potential to play a significant role in decarbonizing various sectors of the economy, particularly the hard-to-abate sectors. In general, it is widely recognized that hydrogen technologies play an important role in deep decarbonization and in the energy transition. However, to reduce global emissions, hydrogen must be produced sustainably, with low life cycle emissions.

1 IEA (2023), Global Hydrogen Review 2023, IEA, Paris https://www.iea.org/reports/global-hydrogen-review-2023, Licence: CC BY 4.0

Low-emission hydrogen can be produced from several energy sources and processes. In the International Energy Agency (IEA)'s Net Zero by 2050 scenario, the average hydrogen production GHG emission intensity should be reduced from 2021's average emission intensity of 12-13 $kgCO_2e/kgH2$ to 6-7 $kgCO_2e/kgH_2$ by 2030, and fall below 1 $kgCO_2e/kgH_2$ by 2050.[2] This can be achieved, among others, using renewables, nuclear, or fossil fuels with high carbon capture and storage rates (more than 90%) and low upstream and midstream GHG emissions.[3]

Regardless of the production pathway, hydrogen possesses the same chemical and physical properties. Therefore, the mitigation of GHG emissions depends on accurately quantifying, monitoring, and reporting emissions throughout the hydrogen value chain. It is essential to use a mutually recognized, harmonized methodology for calculating the GHG emissions associated with hydrogen produced from different sources and technologies to enable accurate comparisons of low-emission hydrogen batches. Ultimately, a common methodology provides market transparency, fosters international trade, supports certification schemes, and informs public policy development.

ISO/TS 19870 provides a unified framework for calculating the GHG emissions intensity, reported as $kgCO_2e/kgH_2$, in the hydrogen value chain. It is designed to harmonize and streamline the partial carbon footprint calculation (the GHG emissions of specific segments of the supply chain) for various technology pathways in the hydrogen supply chain. The methodology encompasses all processes from the extraction of raw material "well" through the transport of hydrogen or hydrogen carrier to the consumption gate (Figure 1). The different uses of hydrogen past the consumption gate are outside the scope of ISO/TS 19870.

2 IEA (2023), Towards hydrogen definitions based on their emissions intensity, IEA, Paris https://www.iea.org/reports/towards-hydrogen-definitions-based-on-their-emissions-intensity, Licence: CC BY 4.0

3 IEA (2023), Towards hydrogen definitions based on their emissions intensity, IEA, Paris https://www.iea.org/reports/towards-hydrogen-definitions-based-on-their-emissions-intensity, Licence: CC BY 4.0

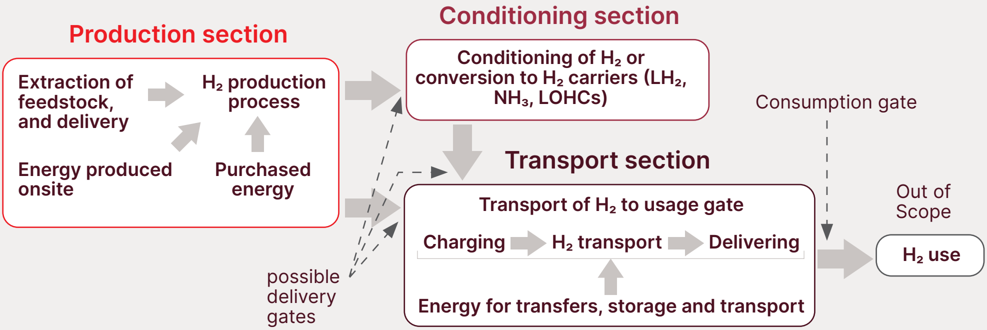

Figure 1

ISO/TS 19870 was developed according to the ISO LCA and CFP International Standards family for the specific case of the hydrogen value chain. In particular, the Dual Approach of the methodology (attributional and consequential) can be beneficial for the creation and assessment of regulations and public policies. For further reading about LCA and CFP, refer to **ISO/TS 19870, Section 2 – Normative References** and the International Reference Life Cycle Data System (ILCD) Handbook.[4] See **ISO/TS 19870 – Figure 1** to understand the relationships among different ISO LCA and CFP standards.

4 European Commission – Joint Research Centre – Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook – General guide for Life Cycle Assessment – Detailed guidance. First edition March 2010. EUR 24708 EN. Luxembourg. Publications Office of the European Union; 2010

How does ISO/TS 19870 align with other environmental standards?

It complements other ISO standards on environmental assessments and management, as it provides specific guidance on the assessment of GHG emissions associated with the hydrogen value chain. It is based on the ISO Life Cycle Assessment (LCA) family of standards, such as ISO 14067 (see **ISO/TS 19870, Section 2 – Normative References** for more information).

Does ISO/TS 19870 cover all stages of the hydrogen value chain?

Yes, ISO/TS 19870 includes a life cycle analysis covering hydrogen production, conditioning, conversion, and transport to consumption gate. It takes into consideration all relevant stages, including upstream methane emissions for hydrogen produced from methane/natural gas, and requires the reporting of capital goods' (CAPEX) emissions. See **ISO/TS 19870, Section 4.2.1 – Product System Boundary** for more information.

Does ISO's methodology feature a threshold to qualify hydrogen as "clean" or "sustainable"?

No. GHG emissions thresholds for qualifying and labelling hydrogen are introduced in self-sovereign national legislation to reflect and serve the policy choices of countries. ISO methodology, therefore, does not include any thresholds or additional qualifications for hydrogen. Instead, it provides a transparent, unified, internationally agreed framework to assess the partial carbon footprint of hydrogen on a life cycle analysis basis covering hydrogen production, conditioning, conversion, and transport to consumption gate.

4. Life cycle assessment, carbon footprint of a product and data quality

Life Cycle Assessment (LCA), as defined by ISO 14040 and ISO 14044, is a method that evaluates the environmental impacts of a product, process, or service throughout its life cycle. Depending on the scope of the study, the boundaries of an LCA range from cradle (comprising the raw material extraction) to grave (the disposal of select product, process, or service). LCA may consider a broad range of different environmental impacts.

Carbon Footprint of a Product (CFP), as per ISO 14067, is a specific case of LCA that focuses exclusively on the GHG emissions of a product. Depending on the scope and boundaries of the study, a partial CFP analysis can be conducted, focusing on particular stages or segments of a product's life cycle rather than assessing its entire life cycle from cradle to grave. This is the case for ISO/TS 19870, which studies the partial CFP of a unit of hydrogen produced, considering the system boundary from the well (cradle) to the consumption gate.

CFP can be divided into four phases:

- **Phase 1: Goal and Scope Definition:** Establishes the study's purpose, defines the system boundaries, and identifies the functional unit.
- **Phase 2: Life Cycle Inventory (LCI) Analysis:** Collects and organizes data on GHG emissions across the selected stages or segments of the product's life cycle.
- **Phase 3: Life Cycle Impact Assessment:** Calculates CO_2e emissions using global warming potential coefficients (GWP) and the data from the LCI phase.
- **Phase 4: Interpretation:** Conducts sensitivity analysis, performs a critical review, and reports the results.

Data quality is an intrinsic part of all phases of a CFP study, that directly impacts the reliability and credibility of the results. High-quality data must be transparent, relevant to the study's goals, representative of the product's life cycle, consistent in terms of measuring and analysis methods, complete with all necessary data points, and accurate to minimize errors and biases. ISO/TS 19870 provides a description of data quality characterization in the Section 4.3.1 – Process Description and Data Quality.

5. Phase 1: Goal and scope definition guidelines

The goal and scope definition phase involves defining the purpose of the CFP study, selecting the approach, setting system boundaries and limitations. This first phase focuses on setting the foundation for the rest of the study. It includes a detailed description of the product system being studied, including its function and the functional unit, which provides a quantified performance measure ensuring comparability of results (see **ISO/TS 19870, Section 4.1.1 – General Principles**). Moreover, according to ISO 14044 and ISO 14067, the LCA and CFP study are flexible and iterative, meaning that, for the results to remain accurate and relevant, the goal and scope definition should be refined as new information becomes available.

ISO/TS 19870 provides methodologies for determining the partial CFP for different hydrogen production, conditioning,[5] conversion,[6] and transport methods, up to consumption gate. The methodology is structured as a main document, which provides the guidelines, in line with ISO LCA family of standards, to develop a partial CFP study for the different pathways and the Informative Annexes that offer examples of the methodology's application. ISO/TS 19870 represents the first step towards establishing a family of ISO standards for partial CFP study in the hydrogen value chain. At this stage, the annexes are informative, with the objective of evolving them into normative annexes for each International Standard derived from ISO/TS 19870. For example, ISO 19870-1 is currently in development and will consist of a main

5 Conditioning refers to changing the physical properties of a species, such as pressuring hydrogen or liquifying it for transport. For more information, see **ISO/TS 19870, Section 3.2.5 – Conditioning**.

6 Conversion refers to changing the chemical conditions of a species, such as converting hydrogen and other species into ammonia or liquid organic hydrogen carriers (LOHCs). For more information, see **ISO/TS 19870, Section 3.2.6 – Conversion**.

text with guidelines for partial CFP studies in hydrogen production, along with normative annexes for technologically mature hydrogen production methods.

For hydrogen production, ISO/TS 19870 encompasses:

- Electrolysis,
- Steam methane reforming with carbon capture and storage,
- Chlor-alkali co-production,
- Steam cracking co-production,
- Coal gasification with carbon capture and storage,
- Biomass waste as feedstock for processes.
- Auto-thermal reforming with carbon capture and storage.

For hydrogen conditioning, ISO/TS 19870 encompasses:

- Compression and liquefaction of hydrogen.

For hydrogen conversion, ISO/TS 19870 encompasses:

- Ammonia as a hydrogen carrier,
- LOHCs as hydrogen carriers.

For hydrogen or hydrogen carrier transport, ISO/TS 19870 follows ISO 19083 and encompasses transport by inland waterway[7], pipeline, rail, road, and sea, as well as all hub operations, such as handling on-site, loading and boarding. Air transport of hydrogen is out of the scope of ISO/TS 19870. For more information on the scope of **ISO/TS 19870**, see **Section 1 – Scope**.

7 This refers to navigable water bodies, such as rivers, canals, lakes, harbours and ports.

5.1. Dual approaches

ISO/TS 19870 acknowledges the Attributional and the Consequential Approaches.

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What's the difference between Attributional and Consequential Approaches? Does ISO/TS 19870 consider both approaches?

Attributional and Consequential Approaches are two LCA and CFP approaches to evaluate the environmental impacts of products or systems. They have distinct goals, scopes, and applications.

The Attributional Approach accounts for the environmental impacts associated with the life cycle of a specific product or system, considering the inputs and outputs within defined value chain boundaries. This approach works as a "snapshot" to assess current environmental impacts.

For example, calculating the carbon footprint of the production of one kilogram of hydrogen by summing emissions from raw material extraction, processing and transport up to the hydrogen production facility, emissions from the hydrogen production processes, emissions from the hydrogen conditioning/conversion processes, transport up to Consumption Gate and allocating the emissions to the hydrogen and the other coproducts. See **ISO/TS 19870, Section 4.1.2 – Attributional Approach** for more information.

The Consequential Approach evaluates the environmental impacts resulting from changes due to decisions or shifts in production and consumption patterns. It includes indirect effects and often extends beyond original system boundaries involved with product value chain. This method is mostly used for policy impact analysis, planning and strategic decision-making.

For example, evaluating the avoided emissions by producing hydrogen from municipal solid waste (MSW) in comparison to the baseline scenario of MSW that would otherwise decay in landfills. See **ISO/TS 19870, Section 4.1.3 – Consequential Approach** for more information.

Both Attributional and Consequential Approaches are acknowledged in ISO/TS 19870:2023.

5.2. System boundaries

ISO/TS 19870 considers a well to consumption gate system boundary. This approach covers all direct[8] and indirect[9] emissions, from the acquisition and transport of the raw materials to the delivery of hydrogen at the Consumption Gate (see **ISO/TS 19870, Figure 3**). Capital expenditure (CAPEX) emissions, if clearly proven insignificant, may be excluded from the system boundary. Otherwise, they shall be reported separately for information.

The system boundary is subdivided into three sections – hydrogen production, hydrogen conditioning/conversion and hydrogen transport. For example, the upstream boundary limit for the hydrogen conditioning/conversion section is the downstream boundary limit for the hydrogen production section.

Each possible metering point of the products in any section is considered a delivery gate. The methodology is modular, allowing for multiple delivery gates as defined by contractual arrangements. For example, hydrogen production from water electrolysis to be transported as ammonia and cracked into hydrogen right before its consumption. This includes:

- a delivery gate immediately *after* the electrolyser facility operated by company 1, where hydrogen and oxygen are the outputs;
- a delivery gate *before* the ammonia production facility, covering emissions from the hydrogen transport operated by company 2;
- a delivery gate *after* the ammonia production facility operated by company 3, where ammonia is the output;
- a delivery gate *before* the ammonia cracking facility, covering emissions from the ammonia transport operated by company 4;
- a *final delivery gate*[10] after the ammonia cracking facility operated by company 5, where hydrogen will be consumed.

8 Direct emissions refer to GHG emissions from sources owned by or under the control of an entity, e.g. emissions from the combustion of fuels in vehicles used to transport hydrogen from the production facility to the consumption gate for an entity that is responsible for the hydrogen transport operation. It is usually referred to as Scope 1 in the GHG Protocol.

9 Indirect emissions refer to GHG emissions that result from the activity of an entity but occur from sources owned by or under the control of another entity, e.g. emissions from the generation of electricity purchased from a third party to power electrolysers. It is usually referred to as Scope 2, when referring to emissions from the generation of purchased energy, or Scope 3, encompassing all other indirect emissions, in the GHG Protocol.

10 The final delivery gate is the specific gate where hydrogen is delivered for consumption. It is defined as the Consumption Gate in ISO/TS 19870 and it is the last possible system boundary for the application of the methodology. For more information, see **ISO/TS 19870, Section 3.3.8 – Consumption Gate**.

The functional unit, reference unit to which all calculations are related, is defined as 1 kilogram of hydrogen or hydrogen carrier at the conditions and purity required for the next stage in the value chain (see **ISO/TS 19870, Section 4.2.1.1 – General Principles**). Figure 1 (ISO/TS 19870, Figure 4) illustrates the possible delivery gates. The recommended metric for reporting is $kgCO_2e/kgH_2$ for any delivery gate where hydrogen is the product, or $kgCO_2e/kgH_2$carrier for any intermediate gate where the hydrogen carrier is the intermediate product.

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What are CAPEX emissions? How are they accounted for in ISO/TS 19870?

CAPEX emissions are GHG emissions associated with the production and installation of capital assets. They include the GHGs released during the extraction and processing of raw materials, manufacturing of components, transport and building of those assets. ISO/TS19870 requires that CAPEX emissions should be reported separately whenever they are not deemed immaterial. This data is requested for information to enable full LCA assessment while ensuring comparability of the present methodology with those used for the assessment of other energy vectors. See **ISO/TS 19870, Section 4.2.1.1 – General Principles** for more information.

5.3. Environmental impact

ISO/TS 19870 is a partial CFP methodology that assesses the Climate Change Environmental Impact, using the GWP100 expressed in $kgCO_2e$. The main gases considered are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Other GHG, as available in the Fifth Assessment Report (AR5) published by the Intergovernmental Panel on Climate Change (IPCC) – WG1:2013 Appendix 8.A[11], may be used to report CAPEX emissions. The methodology allows for GWP and GTP for other time horizons to be used in addition to GWP100, but they should be reported separately. See **ISO/TS 19870, Section 4.2.3.1 – General Principles**, for more information.

11 Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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What is the metric to measure the impact of GHGs used in the methodology?

The standard measure used in the methodology is GWP100, in $kgCO_2e$. However, the methodology allows for GWP and GTP for other time horizons to be used in addition to GWP100, but should be reported for information separately. See **ISO/TS 19870, Section 4.2.3.1 – General Principles** for more information.

Does ISO/TS 19870 consider hydrogen releases?

ISO/TS 19870 covers the assessment of GHG emissions of hydrogen production, conditioning, conversion, and transport on a life cycle analysis basis as defined by ISO 14067, the generic standard for product carbon footprint. It is consistent with the latest Assessment Reports of IPCC that provide a comprehensive list of greenhouse gases.

Hydrogen releases would translate into an increase of the GHG footprint of hydrogen delivered as the quantity of GHG emissions accounted considers the total amount of hydrogen produced. In addition, reporting of the quantities of hydrogen produced, stored, and delivered at each delivery gate up to consumption gate can provide visibility on hydrogen releases.

Government and industry agree on the need for advancing design, monitoring, measurement, and repair systems as those will play an essential role in providing robust, reliable data and informing modelling tools for hydrogen releases.

5.4. Cut-off criteria

Cut-off criteria are used to assess which processes or inputs may be included or excluded from the study, based on their significance. By removing possible immaterial processes, the study may avoid unnecessary complexity. Notably, a sensitivity analysis may be performed on the environmental significance of the process and all efforts shall be taken to include all processes and flows attributable to the analysed system. All inputs not considered in the study shall be reported. For more information, see **ISO/TS 19870, Section 4.2.2**.

6. Phase 2: Life cycle inventory analysis guidelines

The Life Cycle Inventory Analysis phase for a CFP study involves the acquisition and quantification of data on the inputs and outputs associated with the product system being analysed.

ISO/TS 19870 defines the object of the study as hydrogen produced and conditioned/converted in an industrial plant. The evaluation cycle is the timeframe for which the quantified GHG emissions are representative. This time period must be specified and justified in the inventory, considering both intra- and inter-annual variability, and should reflect the trend over the selected period when possible. If GHG emissions vary throughout the specified time period, data must be collected over an appropriate duration to establish the average GHG emissions for the process (see **ISO/TS 19870, Section 4.2.4 – Evaluation Cycle**, for more information).

According to the defined system boundaries, the CAPEX emissions resulting from the construction and decommissioning of manufacturing plants should be reported separately when significant (see **ISO/TS 19870, Section 4.2.3.1 – General Principles and Section 4.2.1.1 – General Principles**).

6.1. Energy, feedstock and transport services treatment

ISO/TS 19870 provides guidelines for treating emissions from energy, feedstock, and services supplied to processes in the partial CFP study, specifically including electricity, steam, natural gas, and transport services.

6.1.1. Treatment of electricity

Electricity can either be generated on-site, by a specific renewable energy plant or supplied from the grid. According to ISO/TS 19870, Section 4.3.2.5.2, the GHG emissions associated with the use of electricity shall include:

- emissions from the life cycle of the electricity supply system, e.g. upstream emissions for the fuel used to power an on-site generator, such as its transport;
- emissions arising from the supplied electricity, including the electricity metered at the gate of the facility and losses in the electricity generation, transmission and distribution processes.

When electricity is generated and consumed on-site, without being subject to contractual instruments to sell this electricity to a third party, the resulting emissions will be any direct emissions related to generating said electricity as well as the upstream emissions associated with the energy supplied to electricity generator.

When electricity is purchased from the grid, emissions will depend on the selected LCA approach.

- For Attributional Approach, emissions shall follow a dual-reporting requirement, the local-based method or the market-based method.
    - The local-based method reflects the average emission intensity of the grid, such as using grid-average emissions factor data.
    - The market-based method reflects emissions using emission factors from contractual instruments (E.g. energy attribute certificates, direct contracts, or supplier-specific rates). This approach should be prioritized for quantifying emissions if these instruments meet data quality criteria (see **ISO/TS 19870, Section 4.3.1 – Process Description and Data Quality**).
- For Consequential Approach, emissions shall reflect the weighted emission of processes that are expected to respond to the change in demand for electricity. If the electricity is purchased under a contractual arrangement, such as a Guarantee of Origin, from suppliers in excess of what they deliver to the generic market, the emissions factor of these suppliers can be used.

For more information on treatment of electricity, including details on the attributional and Consequential Approaches, see **ISO/TS 19870 Section 4.3.2.5.2**.

6.1.2. Treatment of steam

Steam can be either a process input, as heat or feedstock, or a process co-product. When steam is a process input, emissions assigned to its production and supply shall be allocated to co-products of the hydrogen facility. When steam is a co-product, it shall have a fraction of the inventory of GHG allocated to it.

For more information on treatment of steam, see **ISO/TS 19870, Section 4.3.2.5.3**.

6.1.3. Treatment of natural gas

Natural gas can be used either as energy or as a feedstock. Emissions assigned to its production (including upstream emissions, such as methane upstream emissions) and supply shall be allocated to co-products of the hydrogen facility. ISO/TS 19870, Section 4.3.2.5.4 provides guidance on how to assess the emission factor for the supplied natural gas.

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Does ISO's methodology consider methane emissions associated with natural gas production and transport if hydrogen is produced from natural gas with CCS?

Yes, ISO/TS19870 covers all stages of the life cycle analysis from well to delivery gate, and therefore includes upstream methane emissions for hydrogen produced from methane/natural gas. The specification encourages the use of accurate, granular data and supports advancements in monitoring technologies to improve methane leakage reporting over time. See **ISO/TS 19870, Section 4.3.2.5.4 – Treatment of Natural Gas** for more information.

6.1.4. Treatment of one transport service

ISO/TS 19870, Section 4.3.2.6 provides detailed guidance for the treatment of emissions in One Transport Service, in line with ISO 14083. In general, the assessment of GHG emissions of a transport service shall include GHG emissions by combustion or leakage, regardless of which organization operates them, as follows (ISO/TS 19870, Section 4.2.3.3):

- processes implemented using external handling or transhipment devices for the movement or transhipment of freight; operational processes of hub equipment; vehicle energy provision processes; hub equipment energy provision processes; start-up and idling of vehicles, pipelines, transhipment, and (de)boarding equipment, and cleaning or flushing operations for pipelines.
- both vehicle operational processes and energy operational processes that occur during the operational phase of the lifecycle.
- combustion and/or leakage of energy carriers at vehicle or hub equipment level.
- leakage of GHG used by vehicles or hubs.

For more information on treatment of One Transport Service, see **ISO/TS 19870, Section 4.3.2.6**.

6.2. Emission allocation

The production, conditioning/conversion and transport of hydrogen often produces several wastes and co-products. In that sense, GHG emissions shall be allocated to the different co-products according to a clearly stated and justified allocation procedure (ISO 14067, Section 6.4.6.1).

ISO/TS 19870, Section 4.3.2.8 – Emissions Allocation provides detailed guidelines for emissions allocation.

Some of the relevant terminology in ISO/TS 19870, Section 4.3.2.8 – Emissions Allocation are explained below:

Subdivision refers to dividing the multifunctional process in physically distinguishable, measurable, sub processes.

Virtual subdivision refers to dividing multifunctional processes that are not physically distinguishable, or for which independent, measurable data is not possible or feasible. Virtual subdivision relies on an underlying quantitative relationship to exactly relate the types and amounts of flows associates with at least one of the reference flows.

Combined production and **joint production** refers to the concept in which a single process yields different co-products, fulfilling different co-functions.

In the combined production, the co-functions can be independently varied without affecting more than one co-product, e.g. a truck transporting different feedstock for hydrogen production. The increase or decrease in the amount of a given feedstock is the determining physical cause for the increase or decrease in the fuel consumption and truck's emissions.

In the Joint Production, there is an underlying relationship between the different co-functions and co-products, meaning that a change in one of the co-functions has an effect in another co-function. For example, a water electrolyser co-producing hydrogen and oxygen. The amounts of hydrogen and oxygen cannot be independently varied. It will follow the stoichiometric ratio of 2:1 for hydrogen to oxygen molecules in the water.

System expansion and **substitution** to avoid allocation involves broadening the study's system boundaries to include alternative pathways for the co-products. As a result, the co-product displaces the alternative product and assumes its environmental burden. ISO/TS 19870, Figure 8 exemplifies the system expansion and substitution method.

ISO/TS 19870, Figure 9 displays a detailed decision tree algorithm for allocation methods.

6.3. Carbon capture emissions

According to ISO/TS 19870, Section 4.3.2.1:

If the captured CO_2 is stored (CCS) it is considered a waste; therefore, no emissions are allocated to it. However, the emissions resulting from the capture and storage processes, such as emissions arising from the electricity and/or the fuel use, shall be considered within the inventory of emissions for the hydrogen production.

The captured CO_2 is utilised (CCU):

- in the case of Attributional Approach, the emissions shall not be taken into account, as they do not occur within the system boundaries of the CFP study.
- in the case of Consequential Approach, the system boundaries may be expanded to include other life cycle stages where the utilized CO_2 may be emitted.

7. Phase 3: Life cycle impact assessment guidelines

The Life Cycle Impact Assessment (LCIA) phase in a CFP study aggregates, quantifies and translates the data obtained in the Life Cycle Inventory Analysis into the climate change characterization model for environmental impacts.

ISO/TS 19870 lists a series of required items to be provided for each stage of the hydrogen value chain present in the partial CFP study, including a description of the process, emissions inventory, allocation methods, results of sensitivity analysis, and references used in the study. See **ISO/TS 19870, Section 4.3.1** for the complete list of required items.

7.1. Calculating the total GWP

ISO/TS 19870 uses the Global Warming Potential over 100 years (GWP100), expressed in kgCO_2e, as the characterization factor, as specified in the Goals and Scope definitions. Therefore, all emissions evaluated in the Life Cycle Inventory Analysis must be converted to kgCO_2e for comparison and analysis. The total emission in kgCO_2e for a given process is calculated by multiplying the mass (in kg) of each greenhouse gas emitted in said process by its respective GWP100 coefficient, and then summing these values, as detailed in ISO/TS 19870, Table 2 and Equation 1.

The total GHG emissions in kgCO_2e will be the sum of the emissions for each stage of the value chain, as illustrated below and in ISO/TS 19870, Equation 2:

$$E_{\text{emissions inventory production}} =$$

$$E_{\text{emissions inventory conditioning}} + E_{\text{emissions inventory transport}}$$

Each of those emissions include all direct and indirect emissions within the system boundary from well-to-gate, and may be broken down into the following emission categories:

$$E_{\text{emissions inventory (production/conditioning/transport)}} = E_{\text{combustion emissions}} + E_{\text{fugitive emissions}} + E_{\text{industrial processes emissions}} + E_{\text{energy supply emissions}} + E_{\text{upstream emissions)}}$$

Combustion emissions refers to emissions arising from the combustion of relevant solid, liquid and/or gaseous fuels, in tonnes of CO_2e. See **ISO/TS 19870, Section 4.3.2.2 – Combustion Emissions**, for more information and description of how to calculate these emissions.

Fugitive emissions refers to emissions arising from structural and operational losses due to the technology deployed and plant management. It includes, but is not limited to, all leakages (e.g. CO_2 leakages), accidental losses or other losses due to incorrect management plant operations, in tonnes of CO_2e. See **ISO/TS 19870, Section 4.3.2.3 – Fugitive Emissions** for more information and how to calculate these emissions.

Industrial processes emissions refers to emissions arising from specific GHGs throughout a variety of industry activities, such as in cooling systems or in electrical equipment, in tonnes of CO_2e. Depending on the nature of the GHG, these emissions may be limited to the reporting of capital good emissions. See **ISO/TS 19870, Section 4.3.2.1 – General Principles** for the list of gases considered in ISO/TS 19870. **See ISO/TS 19870, Section 4.3.2.4 – Industrial Process Emissions** for more information and how to calculate Industrial Processes emissions.

Energy supply emissions refers to emissions, in tonnes of CO_2e, arising from the supply of electricity, steam, natural gas (including emissions from gas transport and fugitive emissions, such as methane upstream emissions) and transport services for the specific stage of the hydrogen value chain. See

Section 5.1 and **ISO/TS 19870, Section 4.3.2.5 – Energy Supply Emissions** for more information and how to calculate these emissions.

Upstream emissions refers to other upstream emissions not included in the energy supply emissions, in tonnes of CO_2e, associated with any other input to a system, based on the cut-off criteria. These emissions may include upstream emissions for inputs such as coal, oxygen gas, salts for electrolysis, chemicals used for water treatment etc. See **ISO/TS 19870, Section 4.3.2.7 – Upstream Emissions** for more information and how to calculate these emissions.

8. Phase 4: Interpretation guidelines

The interpretation phase is the final phase of the CFP study. According to ISO 14067, it involves analysing and interpreting the results obtained from the two previous phases, Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) phases, to identify significant issues, evaluate data quality, perform sensitivity and uncertainty analyses, and draw clear conclusions for the CFP study. It may be possible that, during the Interpretation phase, it is perceived that the Goals and Definitions could be refined to fill gaps in the study and enhance its precision.

During the Interpretation Phase, ISO/TS 19870 recommends that the applicant prepare a Life Cycle Assessment Report[12] (see **ISO/TS 19870, Section 4.4 – Life Cycle Assessment Report**). ISO/TS 19870 also leaves room for the performance of a Critical Review,[13] according to **ISO/TS 14071 (see ISO/TS 19870, Section 5 – Critical Review**).

12 A comprehensive report documenting the findings, approaches, methodologies, data quality criteria, assumptions and limitations, among others, of a CFP study.

13 Review of the CFP study compilation, generally by independent experts, to ensure that the findings of the CFP study are transparent, technically accurate and consistent with ISO standards.

9. Annexes and next steps

Eleven annexes are published as complementary information to the ISO/TS 19870. The annexes are:

Hydrogen production:

- ISO/TS 19870, Annex A – Hydrogen production pathway – Electrolysis
- ISO/TS 19870, Annex B – Hydrogen production pathway – Steam methane reforming (with carbon capture and storage – CCS)
- ISO/TS 19870, Annex C – Hydrogen production pathway – Chlor-alkali
- ISO/TS 19870, Annex D – Hydrogen production pathway – Steam cracking
- ISO/TS 19870, Annex E – Hydrogen production pathway – Coal gasification (with carbon capture and storage – CCS)
- ISO/TS 19870, Annex F – Hydrogen production pathway – Biomass waste as feedstock (with carbon capture and storage – CCS)
- ISO/TS 19870, Annex G – Hydrogen production pathway – Auto thermal reforming (with carbon capture and storage – CCS)

Hydrogen conversion:

- ISO/TS 19870, Annex H – Hydrogen conversion pathway – Ammonia as a hydrogen carrier

Hydrogen conditioning:

- ISO/TS 19870, Annex I – Hydrogen conditioning pathway – Liquid hydrogen as carrier
- ISO/TS 19870, Annex J – Hydrogen conversion pathway – LOHCs as hydrogen carrier

Annex K, which assesses GHG emissions for hydrogen purity lower than 99mol%.

Except for Annex K, all annexes provide examples of the application of the methodology for different hydrogen pathways. In general, they follow the same structure, composed of process description and overview, emission sources and inventory, emissions allocation and information to be reported. At this stage, all the annexes are informative, and given as illustrative examples.

ISO/TS 19870 is the first step towards the final goal of developing a series of ISO standards to assess the CFP of the hydrogen value chain. ISO International Standard 19870-1 is under development and covers the hydrogen production stage, outlining normative annexes for each pathway, including new ones. The following standards, ISO 19870-2, -3, -4 etc. are still under discussion and will cover the conversion, conditioning and transport processes. As such, the content of this document is subject to change based on future revisions.

10. Questions and answers

The goal of this Q&A section is to address common concerns, provide additional information and reinforce key points of the methodology. It was created by compiling and expanding on frequently asked questions perceived by ISO and ISO/TS 19870 stakeholders.

What is ISO? How does it work and how can I join?

ISO is a global standard development organization with a 75-year history in the field of international standardization focused on developing, publishing, or disseminating technical standards to meet the needs of a given field. Those interested in joining an ISO working group should identify and contact their national standards body to express an interest.

Membership often requires demonstrating expertize in the relevant field and being part of the national standards body or a related technical committee. Once involved, those interested can participate in meetings, contribute to the development of standards, and engage with other experts to work on the creation and revision of international standards. ISO encourages the participation of a diverse range of experts and stakeholders in the development of standards. ISO's consensus-based approach relies on the input and collaboration of these varied participants to ensure that the standards are comprehensive, balanced, and applicable globally.

What is UNIDO?

UNIDO is a specialized agency of the United Nations with a unique mandate to promote, dynamize and accelerate industrial development. Its mandate is reflected in Sustainable Development Goal (SDG) 9: "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", but UNIDO's activities contribute to all the SDGs.

UNIDO's vision is a world without poverty and hunger, where industry drives low-emission economies, improves living standards, and preserves the livable environment for present and future generations, leaving no one behind. UNIDO provides support to its 172 Member States through four mandated functions: technical cooperation; action-oriented research and policy-advisory services; normative standards-related activities; and fostering partnerships for knowledge and technology transfer.

What is the main technical committee leading the work on hydrogen within ISO?

ISO/TC 197, *Hydrogen technologies* leads standardization in the field of systems and devices for the production, storage, transport, measurement, and use of hydrogen. ISO/TC 197, *Hydrogen technologies*, SC 1, *Hydrogen at scale and horizontal energy systems*, focuses on the standardization of large-scale hydrogen energy systems and applications, in particular, aspects of sustainability, testing, certification and placement, and coordination with relevant standardization bodies and stakeholders.

What is ISO/TS 19870?

ISO/TS 19870 is a technical specification that provides a methodology for determining the GHG emissions associated with the production, conditioning, and transport of hydrogen up to consumption gate. It provides a comprehensive framework for assessing the partial carbon footprint of hydrogen technologies, from well to consumption gate, covering all life cycle stages of hydrogen.

Why is ISO/TS 19870 important?

Countries have been introducing national legislation related to hydrogen, making different policy choices with respect to the types of hydrogen that they intend to deploy and support, in particular, based on different GHG emissions intensity thresholds. ISO/TS 19870 is critical for standardizing GHG emissions assessment across various hydrogen production and delivery pathways. It supports global climate goals by offering a transparent, consistent benchmark for evaluating and comparing hydrogen's environmental impact. This is essential for fostering trust among investors and aiding in hydrogen certification.

Who should use ISO/TS 19870?

Stakeholders in the hydrogen value chain, such as hydrogen production, conditioning, conversion, and transport, including technicians, entrepreneurs, policymakers, investors, and certification bodies.

What are the main benefits of standardizing GHG emissions assessment with ISO/TS 19870?

ISO/TS 19870 provides a standardized framework for GHG emissions assessment in hydrogen technologies. Thereby it:

- enhances transparency and comparability in the hydrogen market,
- supports informed decision-making and policy formulation on hydrogen deployment,
- facilitates the certification and sustainability assessment of hydrogen,
- contributes to global efforts by understanding the potential role of hydrogen to mitigate climate change.
- What is the role of ISO’s methodology for GHG emissions assessment of hydrogen for global investors?
- ISO’s methodology will play a critical role in helping build trust in the sustainability of hydrogen as a new globally traded commodity to:
- foster transparency at global level for investors and end users,
- help build consumer trust and support bankable offtake,
- advance competition between different hydrogen pathways based on their GHG footprint,

- provide a common global benchmark methodology for all low-emission hydrogen pathways, enabling tool to implement sovereign policy choices of countries at national level.

This methodology should be used to compare the emissions in the hydrogen value chain from different pathways in a quantitative, transparent, and comprehensive approach. ISO International Standards are voluntary and do not replace national requirements or laws by sovereign nations, with which standards users are understood to comply and that take precedence. Moreover, national laws may refer to ISO standards.

How does ISO/TS 19870 align with other environmental standards?

It complements other ISO standards on environmental assessments and management, as it provides specific guidance about the assessment of GHG emissions associated with the hydrogen value chain. It is based on the ISO LCA family of standards, such as **ISO 14067 (see ISO/TS 19870, Section 2 – Normative References** for more information).

Does ISO/TS 19870 cover all stages of the hydrogen value chain?

Yes, ISO/TS 19870 includes a life cycle analysis covering hydrogen production, conditioning, conversion, and transport to consumption gate. It takes into consideration all relevant stages, including upstream methane emissions for hydrogen produced from methane/natural gas, and requires the reporting of CAPEX emissions. See **ISO/TS 19870, Section 4.2.1 – Product System Boundary** for more information.

Does ISO's methodology feature a threshold to qualify hydrogen as "clean" or "sustainable"?

No. GHG emissions thresholds for qualifying and labelling hydrogen are introduced in self-sovereign national legislation to reflect and serve the policy choices of countries. ISO's methodology therefore does not include any thresholds or additional qualifications for hydrogen – it provides a transparent, unified, internationally agreed framework to assess the partial carbon footprint of hydrogen on a life cycle analysis basis covering hydrogen production, conditioning, conversion, and transport to consumption gate.

What's the difference between Attributional and Consequential Approaches? Does ISO/TS 19870 consider both Attributional and Consequential Approaches?

ISO/TS 19870 acknowledges Attributional and Consequential Approaches.

Attributional and Consequential Approaches are two LCA and CFP approaches to evaluate the environmental impacts of products or systems. They have distinct goals, scopes, and applications.

The Attributional Approach accounts for the environmental impacts associated with the life cycle of a specific product or system, considering the inputs and outputs within defined value chain boundaries. This approach works as a "snapshot" to assess current environmental impacts, e.g. calculating the carbon footprint of the production of one kilogram of hydrogen by summing emissions from raw material extraction, processing and transport up to the hydrogen production facility, emissions from the hydrogen production processes, emissions from the hydrogen conditioning/ conversion processes, transport up to Consumption Gate and allocating the emissions to the hydrogen and the other coproducts. See **ISO/TS 19870, Section 4.1.2 – Attributional Approach**, for more information.

The Consequential Approach evaluates the environmental impacts resulting from changes due to decisions or shifts in production and consumption patterns. It includes indirect effects and often extends beyond original system boundaries involved with the product value chain. This method is mostly used for policy impact analysis, planning and strategic decision-making, e.g. evaluating the avoided emissions by producing hydrogen with CCS from municipal solid waste (MSW) in comparison to the baseline scenario of MSW that would otherwise decay in landfills. See **ISO/TS 19870, Section 4.1.3 – Consequential Approach** for more information.

What are CAPEX emissions? How are they accounted for in ISO/TS 19870?

CAPEX emissions are GHG emissions associated with the production and installation of capital assets. CAPEX emissions include the GHGs released during the extraction and processing of raw materials, manufacturing of components, transport and building of those assets. ISO/TS 19870 requires that CAPEX emissions should be reported separately whenever they are not deemed immaterial. This data is requested for information to enable full LCA assessment while ensuring comparability of the present methodology with those used for the assessment of other energy vectors. See **ISO/TS 19870, Section 4.2.1.1 – General Principles** for more information.

What is the metric to measure the impact of GHGs used in the methodology?

The standard measure used in the methodology is GWP100, in $kgCO_2e$. However, the methodology allows GWP and GTP for other time horizons to be used in addition to GWP100, but they should be reported separately. See **ISO/TS 19870, Section 4.2.3.1 – General Principles** for more information.

Does ISO/TS 19870 consider hydrogen releases?

ISO/TS 19870 covers the assessment of GHG emissions of hydrogen production, conditioning, conversion, and transport on a life cycle analysis basis as defined by ISO 14067, the generic standard for product carbon footprint. It is consistent with the latest Assessment Reports of IPCC that provide a comprehensive list of greenhouse gases.

Hydrogen releases would translate into an increase of the GHG footprint of hydrogen delivered as the quantity of GHG emissions accounted considers the total amount of hydrogen produced. In addition, reporting of the quantities of hydrogen produced, stored, and delivered at each delivery gate up to consumption gate can provide visibility on hydrogen releases.

Governments and industry agree on the need for advancing design, monitoring, measurement, and repair systems as those will play an essential role in providing robust, reliable data and informing modelling tools for hydrogen releases.

Does ISO's methodology consider methane emissions associated with natural gas production and transport, if hydrogen is produced from natural gas with CCS?

Yes, ISO/TS 19870 covers all stages of the life cycle analysis – from well to delivery gate and therefore it includes upstream methane emissions for hydrogen produced from methane/natural gas. The specification encourages the use of accurate, granular data and supports advancements in monitoring technologies to improve methane leakage reporting over time. See **ISO/TS 19870, Section 4.3.2.5.4 – Treatment of Natural Gas** for more information.

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