INDUSTRIAL DEEP DECARBONISATION
AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

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SETTING A FOUNDATION FOR CARBON CAPTURE AND STORAGE IN PRODUCT LIFE CYCLE ASSESSMENT

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Acknowledgements and disclaimer

This white paper was developed based on a series of discussions held in 2024 involving representatives from the IDDI member governments, and a number of organizations, including: C-Change Labs, CEM CCUS Initiative, CEM Secretariat, Cement Association of Canada, Global CCS Institute, Global Cement and Concrete Association, Jernkontoret, Mission Innovation Carbon Dioxide Removals Mission, NDE Germany, VDZ Technology GmbH (Association of German Cement Works), World Steel Association, Wirtschaftsvereinigung Stahl (German Steel Association).

Editor's note:

Leakage: when used in this document refers to physical leakage or venting of CO_2 from point-source, pipelines or storage, and not the concept of carbon leakage where manufacturing emissions move from one country to another due to environmental policies in the home country.

Executive summary

Carbon capture and storage (CCS) will play a critical role in industrial decarbonization, particularly to abate greenhouse gas (GHG) emissions inherent to industrial processes and to remove biogenic carbon from the atmosphere. In applications relevant for cement and steel manufacturing, CCS technology is in a nascent state with high capital and operational costs, and a combination of policy, standards, definitions, and labelling mechanisms are required to accelerate technological deployment.

Robust, trustworthy and transparent information about the environmental credentials of industrial products is a key foundation for green markets. Such information enables market actors to differentiate and trade low emission products, but for this information to be understandable and enable comparisons between products, it must conform to interoperable methodological standards.

GHG emission accounting standards for CCS are emerging in several jurisdictions to support emissions trading schemes and other national regulations. Guidance is also emerging from organisations including the Greenhouse Gas Protocol and Science Based Targets initiative to inform non-regulatory reporting methods. Despite increased international focus on GHG accounting standards for products, there is little ongoing international work to integrate CCS data into product life cycle assessments (LCA). Doing so would enable manufacturers using CCS to demonstrate the green credentials of their products using environmental product declarations (EPDs), and attract green premiums for those products from environmentally motivated buyers. Without guidance to support such reporting, buyers may not have enough confidence in manufacturers' claims to make green procurement decisions.

To provide a common basis for guidelines to measure and report CCS at the product level, this report highlights the key questions that must be addressed and the stakeholders that could carry this work forward. By coalescing around a common understanding of how CCS should be integrated in product LCA, governments, industry and standard setting organizations can contribute to building a coherent reporting framework and avoid developing duplicative and potentially misaligned standards. This work is in a fledgling state and as new findings are obtained through sector-specific studies on CCS, it is important that standards development processes are flexible and open to consideration of this information.

The scope of this paper is limited to integrating point-source CCS data into product category rules (PCRs) that guide the creation of EPDs for cement, concrete and steel products. Efforts should be made to engage organisations and other sectors also developing guidance for CCS and carbon capture and utilization accounting.

The role of standards and CCS in industrial decarbonization

There is an urgent need for policies that enable deep decarbonization of heavy industry to accelerate the global energy transition. The UNFCCC estimates that global emissions must fall by 7 per cent annually between now and 2030 to keep a 1.5-degree goal within reach, however, emissions continue to rise at a rate of 1.5 per cent each year.[1]

Collectively, the cement and steel sectors account for over 10 per cent of global emissions[2] and just under 50 per cent of industrial emissions.[3] Existing abatement mechanisms such as fuel switching, energy and resource efficiency, and product design, can drive significant reductions in industrial emissions, but deployable solutions are required to abate emissions inherent to industrial processes and drive step-change reductions in manufacturing emissions.

Across the economy, carbon capture, utilization and storage (CCUS) has been identified as essential to achieve deep decarbonization and net-zero emissions.[4] The Global Cement and Concrete Association (GCCA) expects CCS to play a major role in cement decarbonization by 2050 alongside other improvements and efficiencies in the concrete value chain.[5] The World Steel Association recognizes CCS as part of a broad portfolio of technological options required to transition to a low carbon economy.[6]

As of November 2024, CCS technologies have largely been deployed in applications with high CO_2 concentrations such as natural gas processing and ethanol production. Applications with low CO_2 concentrations and high levels of other pollutants in the flue gas, such as in the cement, steel and power sectors, have seen progress on point-source carbon capture for utilization and storage,[7] but are not yet commercialized in scenarios where CO_2 is stored without enhanced oil recovery. While there is recent progress, much of the essential infrastructure for wide scale deployment, such as pipelines and ports, are currently limited in scale with significant increases required. Attracting investment for CCS and infrastructure deployment will rely on policy development and business models, stringent emission reduction requirements for industry, financial incentives for reducing CO_2 emissions, and mechanisms that enable manufacturers to assure buyers that products have low embodied emissions and justify green premiums.

In 2023, the IDDI Secretariat highlighted the need for transparent and robust emissions accounting standards,[8] and for guidance to support the integration of CCUS data into product LCAs. High quality information about the embodied emissions of industrial products will underpin definitions for low and near zero emission products, and in turn, public and private sector organizations can use definitions to set environmental performance requirements and map trajectories towards near zero emission procurement. This information can also inform labelling schemes enabling differentiation of low emission products on the market.

Considering the global market for steel products and regional markets for cement, methodologies for calculating net emission reductions from the whole CCS chain, fully accounting of any emissions along the chain, should be built on a common framework. Whilst a universal methodology would be an ideal solution, it is important to recognise that standard setting organizations have different geographic scopes and unique internal processes. These organizations develop standards to meet the requirements of their members and the resulting rules and requirements may differ. Activities should be coordinated to the greatest extent possible to ensure a common methodological basis, avoid duplication of work and prevent major misalignments between resulting standards.

Overview of relevant standards and work streams

Emissions accounting standards have attracted significant interest from governments and industry as a critical enabler for deployment of low emission technologies. Where they exist, CCS accounting methodologies are designed to support regulatory mechanisms such as tax credits and emission trading schemes. Examining the landscape, there are several areas of CCS reporting activity:

The **European Commission** published the EU CCS Directive in 2009, establishing a legal framework for geological CO_2 storage in Europe.[9] The directive includes requirements for CO_2 monitoring and reporting to support the EU Emissions Trading Scheme Monitoring and Reporting Regulation (EU ETS MRR).[10] The MRR establishes a requirement to monitor and report emissions arising from and stored by CCS activities, and provides a basic methodology for quantifying and reporting CO_2 throughout the CCS network. Data are reported to national authorities annually and aggregated at the facility level before being made public.

The **United States** Environmental Protection Agency is authorized by the Safe Drinking Water Act to develop requirements and provisions for the Underground Injection Control (UIC) Program. The EPA establishes minimum standards and criteria for UIC programs, as most states do not have the ability to regulate and permit underground CO_2 injection.[11] Owners or operators of underground injection wells must follow permitting requirements and standards established by the UIC program authority in their state.

The EPA Greenhouse Gas Reporting Program has established methodologies regarding the supply, injection, and geological storage of CO_2 and collects key information from operators.[12] Operators are obligated to submit annual reports and non-confidential data are made publicly available. This reporting programme is also utilized by the UIC programme and the 45Q CCS tax credit.

ISO/TC 265 develops standards for many aspects of carbon capture and geological storage, including monitoring and verification. ISO/TR 27915:2017 presents an assessment of good practices for GHG MRV across all components of the CCS chain, and an LCA approach for project level emissions and emissions reductions.[13]

CEN/TC 474 aims to build on existing ISO/TC 265 standards, supplementing them with documents tailored to the needs of European stakeholders. The scope of the TC includes accounting for CO_2 across the CCUS value chain and the full lifecycle of CCUS projects.[14]

CEN/TC 350 develops standards for the assessment of sustainability aspects of new and existing construction works.[15] The TC is currently drafting a new technical specification (TS) to provide a framework for the use of chain of custody models for inputs and outputs, including material, energy and emission flows. The IDDI Secretariat is not privileged to access this process, however, this document may provide useful guidance and precedence for integration of CCS data into product LCA methods.

Mission Innovation Carbon Dioxide Removals (MICDR) has a technical track on CCS lifecycle assessment and techno-economic analysis (LCA-TEA).[16] Action 1.2 of the LCA-TEA technical track aims to develop criteria level guidelines and best practice to guide the development of LCA standards for carbon capture and removals. The action plan covers a broad scope of LCA accounting criteria, but outcomes may not be directly applicable to industrial CCS applications.

The **CEM CCUS Initiative** is not directly involved in developing accounting methodologies but plays an important role in wider CCUS deployment strategies, policy frameworks, financing, industry collaboration and knowledge sharing.

The **GHG Protocol Land Sector and Removals Guidance**, currently in development, sets out how companies should account for and report GHG emissions and removals from carbon dioxide removal technologies and biogenic products, as well as land management, land use change, and related activities in GHG inventories.[17] Once published, precedents from this guidance can be assessed and used to inform product-level accounting rules.

Summary: There is an increasing amount of activity from governments, standard setters and initiatives on CCS monitoring and reporting standards. Existing methodologies are exclusively designed to calculate emissions at the site level of the emitter, i.e., t CO_2 captured and stored per installation per year, or for whole CCS projects, leaving a gap in the standards landscape for CCS in the context of product level emissions accounting. Technical documents in development by ISO/TC 265, CEN/TC 350 and CEN/TC 474 aim to address this gap although there may be several years before ongoing work is integrated into product LCA standards.

Robust, trustworthy and comparable data will underpin manufacturers' ability to capture value from investments in CCS technology. Governments and industry should consider the development and revision time for international standards (3-5 years) against national CCS strategies and decarbonisation trajectories, where they exist.

Governments with membership across CCS-related initiatives, such as MICDR and the CEM CCUS Initiative, should seek to increase collaboration and knowledge sharing between groups, with the intention of improving outcomes, reducing unnecessary duplication and avoiding misalignment.

Evaluation of identified accounting challenges

This document builds on our experience of product-level emission accounting standards and highlights key considerations to inform future discussion. The following section includes a summary of the challenges to integrating CCS into product level emissions accounting frameworks, and proposals from the IDDI Secretariat on how these should be addressed.

1. Overview

Investor trust in carbon storage claims and consumers' willingness to pay a green premium for low emission products will be built on robust and transparent emissions reporting. Due to the integrated nature of CCS networks, operators within a single network e.g., an industrial cluster, pipeline, port, and injection facility, are likely to take an aligned approach to measuring and reporting CO_2 moving through the system. However, without overarching principles, regulations or guidance from international standards, CCS projects in other regions may establish different methodologies that produce incomparable results. If applied consistently across different materials, a common emission accounting framework, or common principles that underpin accounting frameworks, would ensure that data are interoperable, comparable and can be integrated into product level LCAs and EPDs.

The topics outlined in the following sections should be considered in the development of a methodology, or methodologies for each stage in the CCS chain.

2. Setting the physical system boundary

Background

In product LCA, all emissions arising from the manufacture of a product should be measured and disclosed, and this may include emissions related to capital equipment and other organizational activities. CCS is not directly addressed in existing LCA standards; however, several standards provide general guidance on which CCS-specific rules could be developed.

When capturing CO_2 from industrial processes, it can be treated in two ways; (1) as waste to be stored (CCS), or (2) as an input material for making new products (CCU). This changes how its environmental impacts are calculated. When considering CCS, and CO_2 as a waste, ISO 14040:2006 states that unit processes and flows related to the disposal of process wastes and products should be taken into consideration in a product LCA.[18] ISO 14044:2006 states that unit processes should be initially described to define the nature of the transformation and operations that occur as part of the unit process.[19] From this we can determine that the CCS physical system boundary should include all processes in the CCS network, i.e., capture, treatment, compression, intermediate storage, transport and injection, and associated emissions flows.

The product category rules (PCR) ISO 21930:2017 and EN 15804:2012+A2:2019[20] both follow the polluter pays principle, which requires processes relevant to waste processing to be assigned to the product system that generates the waste.[21] [22] As above, the PCRs would require the physical system boundary to include all CCS processes from flue to reservoir, and for these emission flows to be accounted for by the manufacturer.

From a regulatory perspective, the EU ETS MRR defines a broad physical system boundary for CCS. This includes emissions arising from CO_2 capture processes, intermediate storage and transfer to a CO_2 transport network or to a site for geological storage of CO_2.[23]

Unrelated to waste management or regulations, the embodied emissions of CCS equipment, taking into account manufacture, maintenance, disposal and replacement, may be material to the emission flows in a product LCA. Sensitivity analysis of capital equipment along the carbon chain and consideration of how to approach emissions related to shared infrastructure would provide a basis for inclusion where impacts are material to the product LCA.

Technical committees (TC) developing new accounting guidance should consider the administrative burden and complexity of emission reporting, and how approaches to project and product level reporting frameworks could be built on common frameworks.

Proposal

This section aims to guide standard setters to develop a common physical system boundary for CCS in the context of product LCA. When defining the physical boundary, it is proposed that all physical processes and consumable material inputs are included (see *Table 1*).

Carbon management	Detail

Capture	▪ Energy related to:
	  ▪ CO_2 capture
	  ▪ CO_2 treatment/conditioning
	  ▪ CO_2 compression
	▪ Production, use and disposal (lifecycle emissions) of consumed process inputs such as solvents, sorbents and membranes, among others
	▪ Operation of intermediate storage facilities
	▪ Fugitive/leaked emissions

Transportation	▪ Energy related to CO_2 transport
	  ▪ Pipeline operation
	  ▪ Ancillary services
	  ▪ Vehicles and vessels, and associated on/off loading facilities
	▪ Fugitive/leaked emissions

Stored carbon	▪ Injection facility operation ▪ Fugitive/leaked emissions ▪ Injected CO_2

Table 1: Physical links in the CCS chain

In addition to operational emissions and material inputs, capital equipment should undergo LCA and sensitivity analysis for possible inclusion in product LCA datasets. Ideally, manufacturers of CCS equipment should carry out and publish LCA results to support the development of industry averages for CCS chain equipment and components. Consideration should also be given to how emissions related to shared infrastructure are allocated between operators at the product LCA level. This would support costings and planning for new CCS projects, streamlining future deployment.

3. Setting the temporal system boundary to manage long-term liability

Background

During the storage process, CO_2 is injected into an underground reservoir until it is full, at which point it is sealed. There is a risk, albeit minimal, that CO_2 may migrate or leak from the reservoir during the injection process and after being sealed, and this must be considered in the system boundary.

Existing LCA standards do not provide specific guidelines for setting time limits when considering the environmental impacts of stored CO_2. However, the PCRs offer a potential approach. These rules require manufacturers to account for impacts over a 100-year period after a product is made and its waste is disposed of,[24] suggesting that manufacturers may need to track stored CO_2 for up to 100 years after it is captured or used in a product.

The EU CCS Directive and similar regulations in the US set out a timeline and prerequisites for the transfer of ownership of CO_2 reservoirs from operators to national authorities.[25] This allows for transfer from private to public ownership 20 years after the well has been sealed, provided that ongoing monitoring suggests no leakage has occurred and the CO_2 is stable. In the EU context, where CO_2 is found to leak from a reservoir, this is allocated back to manufacturers and reflected in company level reporting for the EU ETS. Whilst these policies set a useful basis for discussion, some reservoirs may take several decades to complete, potentially making the regulatory and liability timelines difficult to administer in the context of product LCA and environmental declarations.

Proposal

To address the temporal system boundary for CO_2 storage, PCRs must follow a standardized yet flexible methodology that is adaptable to various regulatory and geological contexts, with allowances for updates as new scientific data emerges.

A 100-year time horizon should be adopted, aligning with existing PCRs and EPD best practice. To enable alignment with local regulations and reporting requirements, this approach could incorporate a two-phase accountability system. For example, the emitter would have full responsibility for 20 years, followed by a graduated responsibility scale for the remaining 80 years. Flexibility in the length of each period would allow alignment with local regulations whilst maintaining the 100 year period of responsibility set out in the PCR. This information and any modifications should be clearly reported in the EPD.

A risk-based approach for potential leakage should be developed, using best available geological models to estimate and include probable leakage in initial LCA calculations. Ongoing monitoring and centralized reporting should be required for the initial period, with additional monitoring requirements based on local CCS permitting regulations. To manage uncertainty, LCA results should include uncertainty ranges and use conservative estimates when necessary.

Lastly, clear interim guidelines, including case studies and best practices, should be provided to support practitioners while comprehensive standards are being developed. This approach balances long-term storage considerations with practical limitations, offering a structured framework that can be implemented in the near term while remaining adaptable to future developments.

International coordination between relevant bodies including ISO/TC 265, ISO/TC 59, ISO/TC 207 and CEN/TC 350 is crucial for harmonizing standards and aligning with evolving legal frameworks.

4. Modelling reservoir leaks

Background

Separate from determining the temporal boundary, it is important that the risk and scale of CO_2 leakage from storage reservoirs is understood, calculable, and where material can be accounted for in EPDs. Data from existing geological storage projects suggest that there is a very low risk of CO_2 leakage, however, the scale of current storage projects and datasets is relatively small. As CCS projects proliferate and greater ranges of geological formations are licensed for storage, the risk of leakage may increase. If stakeholders determine that leakage from geological storage is a material risk and that this should be reflected in EPDs, standards must include guidance to calculate it.

Factoring leakage data into product LCA presents a challenge as CO_2 leaks would occur after the after the publication of an EPD, limiting manufacturers' capacity to use primary data in the LCA. An additional challenge (addressed in more detail in CO_2 Chain of Custody section) is how leaked CO_2 can be allocated back to individual manufacturers, when multiple facilities feed CO_2 into a CCS network over an extended period.

Compounding these challenges, few existing CCS projects publish ongoing performance data. A notable exception is the Sleipner Vest gas field operated by Equinor, which makes CO_2 injection, monitoring and leakage data from enhanced oil recovery (EOR)[26] operations available to academics for analysis.[27] Emerging regulations may provide a basis for the widespread collection of leakage data, but accessibility of data by academics or secondary database operators is not certain. The EU CCS Directive and US UIC Program set clear objectives for CO_2 reservoir operators and create an obligation for reservoir operators to report monitoring and activity data to relevant authorities. The EU ETS MRR builds on the CCS Directive, introducing requirements for operators to measure and report leaks so that leaked CO_2 may be counted as payable obligations under the EU ETS.[28] These regulations set a foundation for monitoring and reporting CO_2 leakage data and datasets will become increasingly rich over time. Furthermore, the EU MRR will lead to the development of data frameworks that allocate leaked CO_2 back to manufacturers that use shared networks. However, these policies do not include requirement to publicly disclose this information.

Proposal

To address the quantification of CO_2 leakages in CCS, stakeholders should undertake a comprehensive approach that begins with advocating for open data policies and encouraging the publication of existing CCS datasets, including those from permanent storage and enhanced oil recovery projects. Once there are enough data to be meaningful, this data-driven foundation will enable the development of CO_2 leakage factors and key metrics for reservoir monitoring, leading to the establishment of common global reporting practices and interoperability of datasets.

A leakage classification system based on factors such as duration, rate, location, and geology should be developed to assess environmental impact and tailor monitoring strategies. Classification will support predictive modelling efforts to analyze trends and develop risk management strategies.

The proposal also emphasizes integrating leakage risk assessment into product LCA, including guidance for EPDs and methods for allocating leaked CO_2 among users of shared CCS networks. Finally, it is important to pursue regulatory alignment to ensure consistent reporting requirements and public disclosure of leakage data while protecting sensitive information. This will create a robust framework for managing CO_2 leakage risk in CCS projects and communicating the nature and severity of leaks to the public, enhancing transparency and building trust in CCS technologies.

5. Integrating CCS in the LCA modular system

Existing LCA standards do not provide specific guidance on carbon management. Drawing on existing guidance, CCS could be considered a waste management process, meaning that it is treated in a specific way in the PCRs. However, for the benefits and loads of CCS to be recognised in EPDs in a way that can drive economic returns for a manufacturer, a different approach may need to be taken. This section contains two distinct topics with a related set of proposals.

CCS and LCA modules

The LCA modular system set out in the PCRs ISO 21930 and EN 15804 provides a framework for manufacturers to allocate a product's embodied emissions to different stages of its life cycle. The information in modules A1-A3 is typically used to compare functionally like-products and contains the emission flows arising from

- A1: raw material supply (extraction and processing)
- A2: transportation of materials to the factory
- A3: manufacturing processes

Modules A1-A3 also form the basis for emerging definitions for low and near zero emission products. Despite some variance between the exact system boundaries, definitions from the IEA, Global Cement and Concrete Association (GCCA), ResponsibleSteel and Global Steel Climate Council (GSCC), are broadly based on LCA modules A1-A3. To enable differentiation and trade of low emission products, the net CCS value (the mass of CO_2 stored minus the CO_2 emissions associated with CCS operations) would need to be accounted for in modules A1-A3. For transparency, it may also be valuable for EPDs to include separate disclosure of the mass of CO_2 captured and sent for storage by the manufacturer.

Combined, these disclosures would mean that EPDs effectively account for the reduced carbon intensity of product made in a factory using CCS as compared to products made in a factory not using CCS. In turn this can be reflected in product classification, certification and labelling.

CCS as a service

It is unlikely that most steel and cement manufacturers using CCS will operate CO_2 transportation and storage processes, rather, those without on-site storage options will outsource these processes to a third party. CCS networks will likely be established through multi-stakeholder partnerships, with manufacturers procuring carbon storage as a service from specialised operators.

If this were the case, a simple way to integrate CCS into modules A1-A3 would be to treat CCS as a carbon management service for the manufacturing process. In practice, CCS would be treated like any other service or input except that the embodied emissions added to the system would be negative instead of positive. Manufacturers could procure certificates for 'tonnes of stored CO_2 per declared unit' from storage operators, which must be matched by tonnes of CO_2 captured at that facility and transferred to the same CO_2 transportation and storage network. Storage operators could produce environmental declarations for carbon storage, demonstrating transparency and robustness of their accounting approach.

In this model, the responsibility for calculating operational CCS emissions and modelling leaks during transportation and storage, would fall to the pipeline operator and reservoir storage operator or 'service providers' offering CO_2 transport and storage to the manufacturers. This data could be collated by the storage operator and reported back to the manufacturer, thus simplifying the accounting process for manufacturers. The LCA verification process would require additional steps as verifiers must ensure that the reported tonnes of stored CO_2 is equal to the CO_2 transferred into the network. The system must be monitored to ensure that the mass of stored CO_2 certificates generated and sold matches the mass of CO_2 injected into the reservoir.

In the context of integrating this into PCRs, the polluter pays principle states that processes relevant to waste processing are assigned to the product system that generates the waste until the system boundary between product systems is reached. This could be interpreted to include processes relevant to the net CCS emissions cannot be allocated away to the 'carbon storage sector'. However, manufacturers without on-site storage options would need to purchase CO_2 storage as a condition of adding captured CO_2 into the network. This would include emissions associated with CCS operations (waste processing) and all emission flows would be accounted for by the product system under study. Manufacturers with on-site CO_2 storage would need to follow similar accounting requirements.

Proposal

The net CCS emissions value should be included in the calculation of modules A1-A3 in EPDs for steel, cement and concrete products:

- **Cement EPDs**: the net CCS value should be applied in the calculation of module A1-A3 and disclosed in the aggregated A1-A3 GWP value.
- **Concrete EPDs**: the net CCS value would be included in the cement GWP value. No additional calculations are required because CCS is unlikely to be applied to concrete production. In the IDDI Guidance for PCR Harmonization, it is proposed that concrete EPDs should be required to use manufacturer specific embodied emissions data for cement.
- **Steel EPDs**: In the IDDI Guidance for PCR Harmonization, it is recommended that the GWP of crude steel should be disclosed alongside the GWP of the finished product. The net CCS value up to the crude steel point should be calculated and applied to this figure. This would enable comparison against definitions for low and near zero emission products at the crude steel 'common reporting point'. The net CCS value for the finished product should also be applied to the module A1-A3 GWP value for the finished product.

The net CCS emission value should also be disclosed separately in the EPD. Further development of the 'carbon storage as a service' concept should be carried out, focussing on data flows along the carbon chain, administrative burden for operators, compliance with PCRs for construction materials and other regulatory requirements. Similar methods should be applied to those that own or operate their own storage wells on-site.

A consistent approach is needed between sectors, including cement, concrete, steel, and other CCS using sectors such as chemicals, and oil and gas. This will ensure fairness of approach and avoid unintentional advantages or disadvantages when functionally similar products from different sectors are compared on the basis of embodied emissions.

Also important to consider are the implications for the development of a profitable carbon capture, transportation and storage industry. When considering carbon storage as a service, CO_2 leakage from reservoirs would represent a service system failure. Where manufacturers have procured tonnes of stored carbon and passed that cost to end consumers in the form of a green premium, storage operators may be liable in the event of a proven leak, as is the case under the EU ETS where leaks generate ETS obligations for the manufacturer. Although out of scope of pure emission accounting policy this is an important consideration for the commercialization of CCS and may benefit from input from experts in insurance and financial products. This also has implications for emissions accounting by downstream sectors which may need to retrospectively reflect such leaks in reporting. This work could be considered alongside the development of models to allocate leaks during CO_2 transportation.

6. Biogenic carbon

Background

Bioenergy with carbon capture and storage (BECCS) involves capturing and permanently storing CO_2 from industrial processes where biomass is used as an energy source or process input.[29] The carbon in biomass originates in the atmosphere and is absorbed by plants as they grow. Permanently storing carbon from biomass ("biogenic carbon") is a way to remove CO_2 from the atmosphere and could theoretically lead to industrial processes with negative emissions. The use of biomass and biogenic waste in industrial processes varies by sector and country, most commonly used to substitute fossil fuels in cement kilns but also in blast furnaces. The treatment of BECCS varies between emissions accounting standards, creating misalignment in the reporting landscape.

The Greenhouse Gas Protocol (GHGP) Product LCA and Reporting Standard, and the PCRs ISO 21930 and EN 15804 treat biogenic carbon using a -1/+1 model, meaning that biogenic carbon is treated as a negative emission (-1) when it enters the product system boundary and a positive emission (+1) when it re-enters the atmosphere, equalling zero. This model is widely accepted under the condition that the biomass is demonstrably sustainable.[30] However, EN 15804 rules out accounting for the effects of permanent biogenic carbon storage, meaning that CCS used in conjunction with biomass cannot be included in the calculation of the product's final GWP value.[31] This is aligned with the EU CCS Directive and EU ETS MRR and may weaken the case for investment in CCS technology in sectors and regions where biomass is regularly used in industrial processes. However, the EU Carbon Removals and Carbon Farming (CRCF) regulation,[32] provisionally agreed in April 2024, highlights BECCS as a legitimate and necessary mechanism for removing carbon from the atmosphere and signals a potential policy change.

If the interpretation of EN 15804 is correct, this creates a small but significant difference in the way stored biogenic carbon emissions are accounted for in EPDs compliant with EN 15804 and ISO 21930. Limited deployment of BECCS technology has softened the effect of this misalignment, which may become more salient as the technology approaches commercialization.

Proposal

The benefits and risks of including permanently stored biogenic emissions in product GWP values should be explored through consultation with industry, organisations with expertise in sustainable biomass and provenance, CCS operators, governments and standard setting bodies in different regions. The aim of the process should be to reach a common position on BECCS that creates incentive to invest in CCS technology but does not create a globally unsustainable demand for sustainable biomass. Mechanisms that increase demand for biomass and bio-based fuels should be approached cautiously due to risks around land-use change, deforestation and land competition with food production. As such, the approach should include development of more comprehensive lifecycle assessments for BECCS projects and guidance to limit BECCS deployment to scenarios where it's proven to be beneficial (considering resource and environmental trade-offs).

Additionally, future discussion should consider accounting criteria related to co-processing of biogenic and non-biogenic waste materials in high temperature kilns and furnaces. Following the *polluter pays principle*, these emissions should be accounted for by the manufacturer of the waste material, rather than the operator that combusts the waste material. Where co-processing is combined with CCS, it must be clearly demarcated which entity is able to report the carbon storage.

Progress on the EU CRCF regulation should be observed and European national standards bodies should prepare to propose revisions to EN 15804 to bring it into alignment with ISO 21930 and EU carbon capture and removals regulations. This could serve as a blueprint for other governments in the process of developing carbon storage and removals regulations.

In October 2023, Together for Sustainability (TfS), an initiative from the chemical sector, published a white paper exploring misalignments between biogenic carbon accounting in corporate and product level methodologies. Inclusion of TfS in future discussions would ensure that the outcomes are not inadvertently specific to cement and steel making, and may accelerate progress.

7. CO_2 Chain of Custody

In most cases, carbon capture, transportation and injection networks will serve more than one manufacturing site and a single injection site may serve multiple transportation networks. Chain of custody for CO_2 molecules in a network will be impossible, yet the economic case for investment in CCS will be built on the premise that manufacturers can prove CO_2 arising from their processes has been permanently stored underground. As such, chain of custody mechanisms are required to document CO_2 from the point of emission to storage. This also raises the question of whether stored carbon should have physical chain of custody with the product, or whether virtual chain of custody is acceptable.

CCS network leakage

It is common that when gases[33] are transported over long distances and transferred between pipelines and containment vessels, small quantities of leakage occur. This is a well-documented occurrence in the natural gas sector and it is possible that small amounts of fugitive CO_2 will arise from CCS networks. From an accounting perspective, leakage in the network will create a differential between the mass of captured CO_2 and the mass of CO_2 that reaches the injection point. Depending on the physical layout of the transport network and the mode of transport, CO_2 from one manufacturer may be in transit for longer than CO_2 from another manufacturer and it can be assumed that the longer CO_2 is in transit, the greater the risk of leakage from joints, seals, intermediate storage and auxiliary services such as pumping stations. CO_2 may also be released by intentional venting if the there is a mismatch between the CO_2 supply and network capacity.

Allocating stored and leaked CO_2 back to individual manufacturers will require a chain of custody model based on the mass of CO_2 transferred into the system and the weighted mass of CO_2 stored per manufacturer over time. A mass balance accounting model may provide a workable solution to this challenge if CO_2 is metered at regular intervals throughout the network, and data are readily shared between operators along the carbon chain. However, such accounting schemes can create confusion amongst buyers and care must be taken to develop a system that is robust and transparent.

Providing a basis for this discussion, several approaches to chain of custody are emerging in markets for industrial products. Mass balance models are currently used by a number of steel makers and a book and claim scheme has been launched for sustainable aviation fuels. Industry associations, certification bodies and standard setters are actively developing work programmes in an attempt to provide a common basis for such schemes, to maintain consumer trust and minimize the risk of greenwashing.

In April 2024 the World Steel Association issued principles for chain of custody approaches for GHG emissions in steel making and committed to publishing detailed guidance. In March 2024 ResponsibleSteel launched a public consultation on a new downstream chain of custody standard for material flows (non-emissions). Together, these work streams could provide a useful basis for discussions on the role and design of chain of custody approaches for CO_2 in the carbon value chain.

In the international standards landscape, ISO TC 207,[34] ISO TC 265,[35] and ISO TC 308[36] each have ongoing or proposed work programmes that could connect CCS, chain of custody, and product LCA. In 2017, ISO TC 265 published a technical report on quantification and verification for CCS,[37] and ISO TC 308 is developing requirements and guidelines for mass balance accounting for material flows.[38]

Proposal: CCS network leakage

Although not all of the work programmes are directly related to GHG emissions, the outcomes from each may provide useful precedents for building CCS into product LCA and EPDs. It is proposed that ISO TC 207, 265 and 308 attain mutual liaison membership to facilitate knowledge and progress sharing, and governments should engage national standards bodies to determine if this would be beneficial. Industry organisations, associations and certification bodies should also seek to collaborate and share best practice on the bases for CO_2 chain of custody models, and seek insights from experts in the oil and gas industry.

Physical and virtual chain of custody

This paper considers CCS in the context of processes that are physically linked to the manufacturer producing CO_2. However, stakeholders must determine whether CO_2 storage certificates from CCS projects that are physically unlinked to a manufacturer, such as DAC facilities, are an acceptable mechanism to help manufacturers reach net zero emissions. This should also be considered in the context of book and claim systems, where emissions reductions (e.g., by point-source CCS) at a facility could be sold to a party distinct from the one buying the good, enabling, for example, a cement producer to sell decarbonization value to developers that may use their product but not procure it directly.[39]

Approving the use of the non-physical or virtual CCS-based offsets in product LCA could provide a valuable economic incentive for the deployment of DAC and other carbon capture facilities. This could create opportunities for DAC in areas that are geologically suitable for CO_2 storage but are distant from existing industrial hubs. This could have tangible benefits in emerging markets and developing economies (EMDEs) with low levels of industrialization and provide new opportunities in deindustrialized regions. In theory, this model could meet the concept of net zero emissions, as long as the mass of CO_2 entering the atmosphere in one location is matched by the mass of CO_2 captured and stored in another.

ISO 21930 does not address this topic but EN 15804 explicitly bans non-physical or 'virtual' carbon offset processes on the basis that they are not part of the product system under study.[40] Carbon offsets have historically been difficult to verify and demonstrate that they provide additionality, however, geological storage of CO_2 can be modelled and monitored with more accuracy than nature based and behaviour change offsets.

Proposal: Physical and virtual chain of custody

This raises a number of questions related to incentives for deployment of carbon capture technologies and how stakeholders view the twin challenges of reducing emissions to the atmosphere and reaching net zero emissions.

Stakeholders must determine:

- Whether unabated emissions are acceptable in a system where technological carbon removals are sufficient to balance atmospheric CO_2 levels.
- How a narrow focus on the net reduction of global CO_2 emissions might affect incentives to reduce pollution in industrialized regions.
- How a book and claim system to trade carbon certificates between geographically distant producers and buyers of cement and steel could be administered (learning from sustainable aviation fuels).

Conclusion: A pathway to implementing proposals

This paper highlights key topics that must be considered and addressed to enable integration of CCS into product-level emissions accounting methodologies. At present, emerging, publicly visible methodologies for CCS accounting are not directly focussed on how CCS can be applied to product reporting and this gap makes it more challenging for manufacturers to develop business models for products produced in CCS equipped factories. It is recognised that work to develop technical specifications is ongoing in relevant ISO and CEN TCs and this document can support those processes. The early-stage nature of this work provides an opportunity for collaboration between governments, industry, initiatives and standard setters to create common principles for CCS in product level emissions accounting methodologies, avoiding the need for time consuming and complex harmonization efforts in the future.

The CEM CCUS initiative and MICDR Mission could both provide a neutral forum to host technical discussions amongst governments and industry. In addition, expert organisations such as IEAGHG would provide important expertise and experience from early projects. To avoid duplication of efforts or division of expertise between forums, the IDDI does not intend to host CCS- or CCU-related discussion beyond 2024.

Further attention should also be given to the potential role of emissions accounting for CCU as a short-to-medium term mechanism to incentivize investment in, and deployment of, carbon capture technologies. Whilst short term storage of CO_2 is not a long-term solution to anthropogenic CO_2 emissions, delaying emissions could play a role in bringing forward global peak emissions.

Glossary

Term	Definition	Source
Allocation; Co-output allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems. See Co-output.	ISO 14044:2006, 3.17
Biomass	Material of biological origin, excluding material embedded in geological formations or transformed to fossilized material, and excluding peat.	ISO 21930:2017, 3.7.3
Biogenic	Produced in natural processes by living organisms but not fossilized or derived from fossil resources	ISO 13833:2013, 3.1
Biogenic carbon	Carbon derived from *biomass*	ISO/TS 14067:2013, 3.1.8.2
Carbon capture, utilization and storage (CCUS)	Carbon capture, utilization and storage (CCUS) is a suite of technological processes which involve capturing carbon dioxide [CO_2] gas for use or long-term storage. 1. Carbon capture and utilization (CCU) is a process in which captured CO_2 is used produce a new product. This can displace fossil-derived carbon products with 'green products' such as e-fuels. CCU stores carbon temporarily, depending on the lifespan of the manufactured product. 2. Carbon capture and storage (CCS): a process in which a relatively pure stream of carbon dioxide (CO_2) from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for long-term isolation from the atmosphere. CCS can also be applied to CO_2 from the combustion of biomass (called BECCS) and since plants absorb CO_2 during growth, BECCS offers permanent removal of CO_2 from the atmosphere.	CCU definition adapted from the SR1.5 glossary CCS definition from the IPCC AR6 Glossary
Crude steel	Steel in the first solid state after melting, suitable for further processing or for sale. Synonymous with raw steel. Includes ingots, semi-finished products (slabs, blooms, billets) and steel that is cast.	The World Steel Association glossary
Downstream (in the value chain or life cycle)	Processes following a life cycle stage. Towards the use and end-of-life of a product.	Adapted from ISO 21931-1:2010, 3.2
Environmental Product Declaration (EPD)	An environmental report providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information. An EPD also includes additional product and company information.	ISO 14025:2006

Term	Definition	Source
Global Warming Potential (GWP)	The metric used to quantify heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide (CO_2), typically expressed as kg CO_2e per unit of product, where kg CO_2e represents 'kilograms carbon dioxide equivalent'.	US Government Environmental Protection Agency's Greenhouse Gas Emissions and Sinks Glossary. Definition chosen over for readability when compared against IPCC glossary.
Greenhouse gas (GHG)	Gaseous constituent of the atmosphere, natural or 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.	ISO 21930:2017, 3.7.3
Greenhouse gas (GHG) emission	Release of a greenhouse gas into the atmosphere.	ISO 14064-1:2018, 3.1.5
Interoperable; interoperability	The ability of a system to work with other systems, specifically with the aim of exchanging and making use of information and data. In the context of product category rule harmonization, the term interoperable sets out the ambition that emission accounting requirements in product category rules could be made less flexible and that different product category rules could be harmonized, making the resulting data in EPDs comparable.	As used in the IEA Emissions Measurement and Data Collection for a New Zero Steel Industry (2023) report and the IDDI white paper Driving Consistency in the Greenhouse Gas Accounting System (2023).
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.	ISO 14044:2006
Life Cycle Assessment (LCA)	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.	ISO 14044:2006
Life Cycle Assessment (LCA) module; also upstream module	Distinct stages of the life cycle assessment allowing categorization of greenhouse gas emissions from different sources.	Adapted from EN 15804
Process	Set of interrelated or interacting activities that transforms inputs into outputs.	ISO 9000:2005, 3.4.1
Product	Any good or service.	ISO 14040:2006, 3.9

Term	Definition	Source
Product category and product sub-category	A group of products that share similar characteristics. In this document the product category is construction products. Examples of product sub-categories are steel, cement and concrete.	From ISO 14025:2006: a group of construction products, construction elements, or integrated technical systems that can fulfil equivalent functions
Product Category Rules (PCR)	A set of specific rules, requirements, and guidelines for developing environmental product declarations for one or more product categories.	From ISO 14025:2006
Transparent; transparency	Open, comprehensive and understandable presentation of information.	ISO 21930:2017, 3.3.9
Unit process	Smallest element considered in the life cycle inventory analysis for which input and output data are quantified.	ISO 14040:2006, 3.34
Upstream (in the value chain or life cycle)	Processes preceding a life cycle stage. Towards raw material extraction and production of a product.	Adapted from ISO 21931-1:2010, 3.15
Waste biomass	Substances which the holder intends or is required to dispose of biological origin, such as organic material from plants and animals.	Adapted from ISO 21930:2017, 3.3.11 and 3.7.3

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