EFI FOUNDATION

Integrated Product- and Entity-Level

CARBON ACCOUNTING

PUTTING CONCEPTS INTO PRACTICE

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The EFI Foundation wishes to thank the following individuals for providing independent expert advice to this study project. Their active engagement with the Project Team throughout the project has been enormously important. The participation of the Project Advisory Board members does not imply endorsement of the analysis, approach, or conclusions.

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Foreword

A rigorous system for entity-level and product-based carbon accounting is an essential enabler for tracking greenhouse gas (GHG) emissions along the entire supply chain leading to a product (or service) and its use. As low-carbon markets develop differently across countries and regions, accurate carbon accounting provides the language to enable monetization of product carbon dioxide (CO_2) emissions intensities and inform investment opportunities in further decarbonization. This calls for a policy-agnostic and technology-neutral approach based on well-established financial accounting principles supported by engineering fundamentals.

Integrated entity-level and product-based carbon accounting can be a tool that allows high-fidelity, trusted information transfer along the supply chain, serving both commercial interests and those developing carbon policies and regulations. It is not itself an instrument of policy, but a critical enabler that is missing today.

This paper is intended to provide a concise synthesis of research and analysis developed by the EFI Foundation that presents a methodology and its application to the first of a set of case studies (sustainable aviation fuel, steel, electricity).

The EFI Foundation puts forward a ledger-based system that, at its core, follows carbon stocks and flows by tracking the supply chain history leading to a commercial entity's activity within well-defined spatial boundaries. The ledger can provide a snapshot for any defined period. Future conversion of carbon forms, in many cases, cannot be predicted in location and/or time, and yet this has potential consequences for policy development guided by the impacts of GHG emissions. Consequently, we propose carbon accounting that is based on verifiable results passed along the supply chain, independent of projections about future conversions. Information needed to address the relevant questions for future use must be preserved.

We emphasize that our work builds on considerable literature, including, in particular, the work of Kaplan and Ramanna and the associated E-Ledgers Institute and the work of others on our very engaged Project Advisory Board. However, we also seek to both expand the published frameworks in some dimensions and reduce the approach to practical implementation in terms of entity-level CO_2 emissions and product CO_2 emissions intensities.

Implementing reliable carbon accounting is not simple and will evolve over time as rules and data quality continue to improve and more institutions and industries adopt them. However, we are collectively well past the time of needing to accelerate convergence on

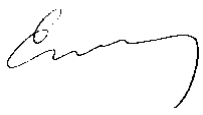
widely accepted carbon accounting principles and practice. We must implement a widely acceptable system soon, while recognizing that it will mature with time.

Recall that modern financial accounting, which provides important guidance for the development of carbon accounting, started a century ago, when the need for more uniform approaches to understanding the financial health of companies was paramount. Adoption of rules and practice remains not entirely uniform across the globe, but common principles and objectives have led to a remarkable system of greatly improved financial transparency of company health and the value of transactions underpinning investment and trade. While the process for evolving a carbon accounting regime can learn from the experience of financial accounting, we do not propose that carbon accounting be assimilated into financial accounting and reporting.

Rigorous and widely accepted principles and practices for integrated entity-level and product-based CO_2 emissions accounting are essential for the growth of markets that can monetize GHG emissions reductions. This is not to say that ambiguities will not arise. For example, CO_2 emissions attributes of the grid typically cannot be uniquely assigned to a particular source or customer at a particular time, but methodologies can be developed and refined over time to provide an accepted approximation for the purposes of accounting. The realization of a carbon-free grid would eventually resolve rule-making ambiguities for carbon accounting. It should not become a fundamental barrier to the design of the accounting system per se. Our goal is development of the tool, not the policy choices that assign value within the system.

We hope that our work contributes to moving a carbon accounting system, built on engineering fundamentals and modeled after financial accounting, to adoption and implementation. A leading set of countries, companies, and financial institutions will be key to supporting, refining, and advancing carbon accounting in the near term. Companies and financial institutions with global reach will be particularly important in this context. The EFI Foundation is eager to collaborate with such institutions and others in a common effort to establish a well-respected CO_2 emissions accounting tool that can advance toward the goal of meeting increasing energy demand while reducing CO_2 emissions.

Ernest J. Moniz



13th U.S. Secretary of Energy
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Introduction

The EFI Foundation, in partnership with Sesame Sustainability Inc., has developed a model ledger-based carbon dioxide (CO_2) emissions accounting system built on pioneering works in academic literature and reduced it to practice through a series of case studies. This ledger-based system combines the engineering fundamentals of carbon mass and energy balances with financial accounting principles.

This model system is comprehensive because it integrates product- and entity-level CO_2 emissions accounting. It is designed to support product-level CO_2 emissions intensity calculations that can be integrated with entity-level reports of total direct CO_2 emissions.

The design also is applicable to other greenhouse gas (GHG) emissions. Implementation can begin with CO_2 and expand to other GHGs over time.

The model system is demonstrated through a series of case study applications to be published separately.

The Opportunity and Need for Integrated Entity-Level and Product-Based CO_2 Emissions Accounting

Global energy consumption has grown by 45% in the past two decades and is expected to continue to rise as markets develop and living standards increase.[1] Supplying enough energy to meet demand will require all types of resources. This is driving competition among the world's largest countries to scale investment across all energy sectors, with emphasis on carbon-differentiated products.

Product-based CO_2 emissions accounting provides a comprehensive measure of the level of CO_2 emissions per unit of product or service over the full supply chain. This provides the needed tool to unlock investment in products and processes to reduce CO_2 emissions while meeting growing market demand for energy.

Governments are taking action to encourage expanded trade in carbon-differentiated products. The European Union Carbon Border Adjustment Mechanism (EU CBAM) is set to take effect in 2026 for an initial set of commodities including cement, iron and steel, aluminum, fertilizer, hydrogen, and electricity. The United Kingdom and Taiwan have announced their own CBAM regimes to begin in 2027. China is looking to set product carbon footprint (PCF) requirements for 100 products by 2027, with many slated for export to markets with carbon-differentiated product preferences.

These countries, and countries that trade with them, have a vital interest in ensuring that carbon-differentiated trade requirements do not adversely impact their competitiveness in global markets. However, there is no single international CO_2 emissions accounting framework at both the entity and product levels, leaving major exporters, such as the U.S., dependent upon varying sets of rules established abroad.

Within the U.S., activity is underway at the state and local government level. The California Low Carbon Fuel Standard, for example, includes carbon intensity measures for incoming fuel supplies from other states and locations.[2] Several other state and local governments are looking at carbon intensity standards for commodities such as concrete procured for public infrastructure.

Existing frameworks for reporting CO_2 emissions at either the product or entity level, including those under the Greenhouse Gas Protocol (GHGP) and the International Organization for Standardization (ISO), remain fragmented and purpose-built.[a] The separate guidelines for reporting product-level and entity-level CO_2 emissions are not integrated, with each falling short of the rigor of accounting standards.

Harmonization of these frameworks into an interoperable CO_2 emissions accounting system is needed, and the timing for action is becoming critical. Harmonization, however, requires more than merely finding commonality among the elements of the current frameworks. Those frameworks fall short of a comprehensive ledger-based CO_2 emissions accounting system consistent with engineering fundamentals and financial accounting principles.

There are two critical challenges: (1) improving the fidelity of the entity-level direct CO_2 emissions totals, including methodologies to provide complete and accurate allocations to products, and (2) developing accounting for product-level CO_2 emissions intensities that can be reconciled to entity-level direct CO_2 emissions reports. Absent a system that accurately, transparently, and verifiably records all CO_2 emissions only once, with allocation of an entity's total CO_2 emissions among product lines, there is significant potential for inconsistency and possible manipulation resulting from the application of different methodologies, limiting investability and credibility of product CO_2 emissions intensity metrics in both market and regulatory contexts.

[a] See Appendix A for a listing of over a dozen current emissions reporting frameworks for reporting CO_2 emissions by geography, by entity, by product and by project. In addition to those shown in Appendix there are, for example, over 37 methods for calculating the product carbon intensity of steel alone.

What Is Comprehensive CO_2 Emissions Accounting?

Comprehensive CO_2 emissions accounting can be broadly defined as a definitive set of ***principles, conventions, and rules*** for quantifying, organizing, and recording transactions affecting CO_2 emissions from all activities contributing to the manufacture of products under the ownership and control of the entity doing the accounting ("the entity").

- The ***principles*** guide all aspects of the design of the accounting system and are drawn from well-established and widely accepted principles of financial accounting. Box 1 summarizes the five general principles adopted for purposes of this report.
- The ***conventions*** include a ledger-based CO_2 emissions accounting framework, incorporating comprehensive carbon mass and energy balances, with entries recorded on the basis of transactions.
- The ***rules*** prescribe the methodologies to be followed for assigning values to the transactions recorded in the ledger. The rules will inevitably evolve as experience is gained over time, just as they have for financial accounting.

Box 1. Principles for ledger design

The ledger design is guided by five general principles drawn from the well-established and widely accepted principles of financial accounting:

- ✓ **Faithful representation** of the sources, stocks, flows, and sinks of the energy, materials, and products that contribute to CO_2 emissions in a manner that is complete, accurate, and free of bias.
- ✓ **Relevance** of all information to the needs of decision-makers (also described as the principle of materiality)[b].
- ✓ **Transparency** of the information so that users have a full understanding of the assumptions and methods used in the accounting of CO_2 emissions.
- ✓ **Comparability** of the total entity-level CO_2 emissions across all entities, as well as comparability of product-level CO_2 emissions intensity among similar products from competing entities. Comparability also includes the principle of consistency of reporting over time for both entity-level and product-level emissions.
- ✓ **Verifiability** of the accounting data through internal reconciliation within the ledger as well as external validation by an independent third-party.

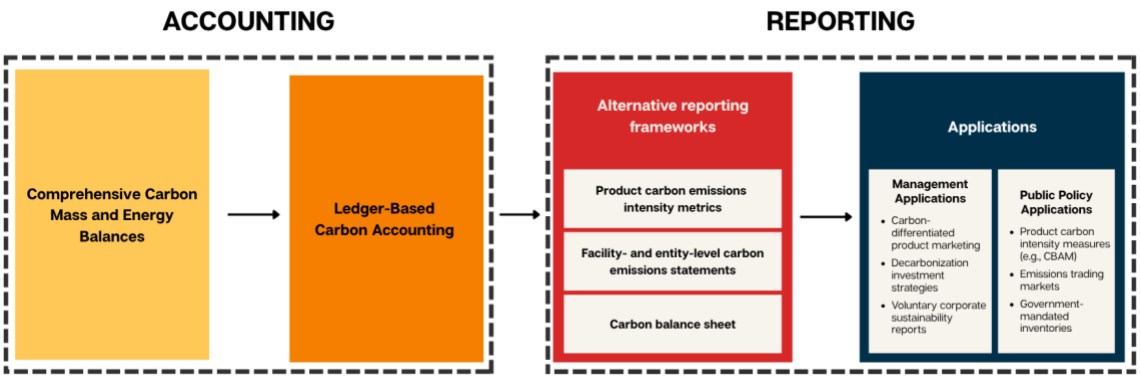
[b] The term "materiality" as used here refers to the size of certain sources with low levels of CO_2 emissions relative to the entity's total CO_2 emissions. It does not refer to the materiality of financial transaction data.

One way to better understand the definition of CO_2 emissions accounting is to consider how it differs from current GHG reporting protocols and from life cycle analysis (LCA).

- **Accounting versus reporting**: Current GHG emissions reporting frameworks are not built on the foundation of an accounting structure. Instead, they are purpose-built, with a specific objective in mind, and rely on inventories that compile data on estimated CO_2 and other GHG emissions to fit that objective. The GHG Protocol Scope 2 and 3 guidelines also require entities to not only inventory their own CO_2 emissions but also collect inventories of GHG emissions from upstream suppliers, downstream customers, and ultimate consumers, without insight or control of the activities contributing to those emissions. Consequently, the reports lack consistency across entities and supply chains because of wide discretion in application of the reporting guidelines. They can leave significant gaps in reporting some sources of CO_2 emissions while simultaneously resulting in duplication of others. Most importantly, they lack the ability to reconcile product-level CO_2 emissions estimates with entity-level total CO_2 emissions in a manner that is complete, accurate and verifiable. Further, the quality of the reported data can vary widely, since the data are compiled after the fact, typically on an annual basis, and often rely upon industrywide averages and modeling estimates rather than entity-specific data.

  The CO_2 emissions accounting system described in this report distinguishes between accounting and reporting by separating the two functions (Figure 1).

Figure 1. Separation of functions of CO_2 emissions accounting and reporting



Source: EFI Foundation.

The separation allows for the design of a CO_2 emissions accounting system that is technology-neutral and policy agnostic, universally supporting a wide variety of reporting formats and applications. The comprehensive accounting framework can

support reports to management on key performance indicators (KPIs) related to CO_2 emissions performance; reports to investors and the public on progress toward sustainability goals; reports on product CO_2 emissions intensity for customers; or emissions reports in response to government reporting requirements.

- **Accounting versus life cycle analysis**: LCA models focus on impacts over the lifespan of a product from cradle to grave. These models are not site-specific and combine broad averages of historical data with projections of future impacts based on assumptions of when and how a product may be stored, converted, or consumed. CO_2 emissions accounting, by comparison, is entity-specific, based on individual transactions within defined time periods, minimizing reliance on industrywide averages wherever possible. If needed, secondary data such as industrywide averages or modeling estimates can be used if they can be reconciled with site-specific data within the framework of the entity's carbon mass and energy balance totals. A recursive approach will improve data fidelity over time. CO_2 emissions accounting can benefit from the insights from LCA models by ensuring that all CO_2-related activities are identified and included in the carbon mass and energy balances.

Ledger-Based Algorithm for CO_2 Emissions Accounting

The central element of a CO_2 emissions accounting system is a set of entity-specific ledgers that can record CO_2-related data on a transactions basis. The ledger-based algorithm originated with the pioneering work of Robert Kaplan and Karthik Ramanna.[3] The algorithm provides that CO_2 emissions are identified and quantified at their source and recorded only once in a ledger, with the ledger data transferred through the various steps in the supply chain along with the products and services to ultimate customers. The ledger system provides a rigorous framework to facilitate transactions-based accounting, providing greater accuracy, transparency, and verifiability. In short, it is the key differentiator between carbon accounting and current GHG emissions reporting frameworks.

Design of a CO_2 Emissions Ledger

A ledger is a dual-sided chart of accounts designed to record CO_2-related transactions. Several different approaches to ledger design have been advanced in academic literature, and the relative merits of each have been vigorously debated. This includes not only the work of Kaplan and Ramanna but also that of Stephen Penman, Stefan Reichelstein, Jimmy Jia et al., and Bastian Distler et al.[4,5 6,7,8,9,10,11,12]

The frameworks for the various carbon accounting systems share common characteristics that distinguish them from current carbon inventory and reporting guidelines. They:

- ✓ Have boundaries that align with the entity's boundaries of ownership and control
- ✓ Are organized on a dual-sided ledger with a chart of accounts
- ✓ Record data on the basis of transactions, by date
- ✓ Emphasize the use of primary, site-specific data
- ✓ Allow for a variety of reports to be drawn from the ledger within defined time periods
- ✓ Enable double-entry bookkeeping of data

The designs of these ledger-based accounting systems, however, differ in how the chart of accounts is organized. The E-ledgers system, for example, has a dual-sided ledger of E-assets and E-liabilities, where the E-asset side consists only of carbon removals (i.e., removal of legacy CO_2 emissions from the environment).[13] The proposed Integrated Corporate Carbon Accounting (ICCA) ledger, by comparison, is organized on the basis of CO_2 emissions assigned to assets within the entity's boundaries and CO_2 emissions liabilities associated with the entity's operations.[14]

The model carbon accounting ledger presented in this report reflects a hybrid structure combining elements of engineering fundamentals with financial accounting standards. Specifically, it consists of a dual-sided ledger of carbon stocks within an entity's boundaries and carbon flows into and out of the boundaries. The ledger also includes data on the carbon content of both incoming materials and outgoing products, along with the CO_2 emissions attributed to the production of those materials and products.[c]

The inclusion of carbon content data together with CO_2 emissions data accomplishes two things: It provides an internal cross-check of conversions of the carbon in fuels and materials to CO_2 emissions within the entity's processes. It also provides baseline information to customers on carbon content of finished products that enables them to estimate and account for future CO_2 emissions from product use.

[c] Attributed CO_2 emissions are those resulting from the processing of raw materials and energy inputs outside the entity's boundary but transferred from suppliers' ledgers to the entity's ledger along with the goods and services provided by the suppliers at the entry gate. See Appendix C for a complete glossary of terms used in this report.

Case Study Reduction to Practice

The ledger-based accounting system is being reduced to practice through a series of operational case studies by the EFI Foundation and Sesame Sustainability Inc. (See Box 2 for a complete list of ongoing case studies). One of these case studies, examining the production of a sustainable aviation fuel (SAF) blend consisting of 50% conventional jet fuel and 50% soybean oil-based fuel, is summarized below.

Box 2. A series of product-based CO_2 emissions accounting case studies

The EFI Foundation, in partnership with Sesame Sustainability Inc., is producing five case studies across three product categories—a fuel, a commodity product, and power—to demonstrate how comprehensive carbon accounting can be applied across diverse sectors with complex supply chains. These include:

- Sustainable aviation fuel (SAF) via hydroprocessed esters and fatty acids (HEFA)
- SAF via alcohol-to-jet (AtJ)
- Steel production via basic oxygen furnace (BOF)
- Steel production via electric arc furnace (EAF)
- Electricity supply, at both the individual generator level (natural gas combined cycle generation plant) and at a utility level that combines multiple generation assets with a transmission and distribution network

SAF-HEFA Site-Specific Case Study

The case study analyzes the production and sale of a 50-50 blend of SAF produced from soybean oil via hydroprocessed esters and fatty acids (HEFA) and conventional jet fuel refined from Bakken crude oil. (A full case study report will be published separately.)

Case Study Description

The SAF supply chain includes three primary feedstock suppliers: a natural gas supplier, an electric utility, and a soybean oil supplier. A hypothetical SAF production facility in Montana converts these inputs through steam methane reforming and the HEFA process into three products: SAF, naphtha, and liquefied petroleum gas (LPG). The SAF producer transports the SAF by truck to a blending terminal, where it is blended with conventional jet fuel[d] before being delivered via pipeline to a nearby airport.

[d] The conventional jet fuel is supplied from a Montana-based refinery that processes Bakken crude oil. The product CO_2 emissions intensity of the conventional jet fuel is modeled separately, and only the results are reported here.

The case study compiles accounting data for an operating period of three months. During this time, the SAF producer processes 35,700 tons of soybean oil to produce 9 million gallons of SAF. The refinery provides 9 million gallons of conventional jet fuel.

Case Study Results

The results of the case study modeling are presented from three perspectives: the carbon mass and energy balances that provide the foundational data for the ledger (*engineer's view*); the CO_2 emissions accounting ledger itself (*accountant's and auditor's view*); and reports of product CO_2 emissions intensity and total CO_2 emissions derived from the ledger data (*management and policymaker's view*).

Carbon mass and energy balances—the engineer's perspective: The comprehensive carbon mass and energy balance for both the SAF and conventional jet fuel supply chains provides the essential data to support the ledger-based carbon accounting. The principal data elements are illustrated in Figure 2.

Figure 2. The carbon mass and energy balance from an engineering perspective

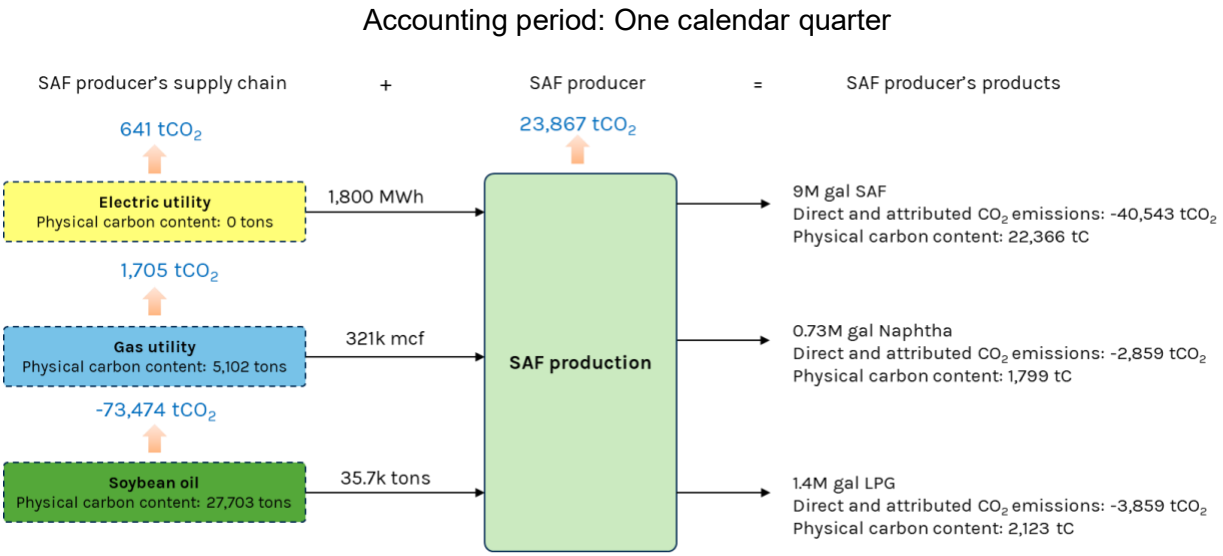


Figure 2 Note: The carbon mass and energy balance identifies all carbon-related flows and stocks, documenting the relationship that the total incoming physical carbon content plus the CO_2 emissions attributed to it, minus the direct CO_2 emissions within the entity's production process, equals the total outgoing physical carbon content of products plus the CO_2 emissions allocated to these products. The numbers shown in the figure are not in complete balance because other forms of carbon emissions, namely methane (CH_4), carbon monoxide (CO), and volatile organic compound (VOC) emissions are excluded for simplicity. (tC = ton of carbon; mcf = 1,000 cubic feet; tCO_2 = ton of carbon dioxide; MWh = megawatt-hours; gal = gallon.) Source: Sesame Sustainability.

The carbon mass and energy balances identify and quantify all of the sources, conversions, and ultimate disposition of all forms of carbon in the SAF production process. The data on incoming feedstocks and energy supplies includes CO_2 emissions attributed to the preparation of the feedstocks as well as their carbon content. Note that soybean oil feedstock has a negative CO_2 emissions value based on its biogenic production cycle[e]. Also note that electricity flows do not contain carbon per se, but electricity does carry with it the CO_2 emissions attributed to its generation.[f] The SAF production process results in the conversion of the carbon content of natural gas to direct CO_2 emissions from the production facility. The direct CO_2 emissions from the conversion process are combined with the attributed CO_2 emissions from the preparation of the feedstock materials, and the combination is allocated to products. The production process yields three products—SAF, LPG, and naphtha—each with its own mass, energy content, and carbon content. Attributed and direct CO_2 emissions are then allocated across the three products on the basis of their energy content.

Ledger-based CO_2 emissions accounting—the accountant's and auditor's perspective*:* The carbon mass and energy balance data provide the inputs for the transactions to be recorded in the SAF producer's accounting ledger. This section presents a ledger organized by stocks and flows, and a separate ledger perspective derived from E-ledgers concepts.

Stocks and flows ledger perspective: The ledger records each transaction, as corresponding debits and credits, to the two sides of the ledger. One side records transactions affecting stocks (i.e., the level of attributed CO_2 emissions and carbon content held within the entity) and the other records transactions affecting flows (i.e., attributed CO_2 emissions, direct CO_2 emissions and carbon content entering and exiting the entity boundaries). The ledger then records the allocation of all incoming attributed CO_2 emissions and all direct emissions to the slate of the three products. This in turn supports the calculation of the product CO_2 emissions intensity for each product that is sold to customers. In the case of SAF, the product is then blended 50-50 with conventional jet fuel for the airline customer. A summary of the ledger-based transactions is shown in Table 1.

[e] The soybean oil feedstock is assigned a negative CO_2 emissions value based on its biogenic production cycle. The net negative CO_2 emissions estimate for the soybean oil are derived from the GREET life cycle model.

[f] For this case study, grid electricity emissions intensity factors are based on GREET 2024 "wall outlet" emissions calculated at the user site. For Montana specifically, the grid mix was derived from NREL Standard Scenarios 2023 Mid-case projections for 2024, which assumes the following generation portfolio: 40% hydroelectric, 34% coal, 22% wind, 4% solar photovoltaic, and 1% natural gas. The emissions factors include both upstream and direct emissions associated with electricity generation and delivery.

Table 1. Summary of transactions in stocks and flows format: CO_2 emissions ledger in double-entry bookkeeping

SAF producer ledger in stocks and flows format

CO_2 Stocks (CO_2 in materials assets held within entity) (tCO_2)		Flows of CO_2 emissions (entering and exiting entity boundaries) (tCO_2)	
Beginning Stocks Balance (A)	*0*	*Beginning Flows Balance (A)*	*0*
Stocks Added (before production)		Flows Added (before production)	
Attributed CO_2 emissions to soybean oil supply	-73,474	Attributed CO_2 emissions transferred in	-71,128
Attributed CO_2 emissions to natural gas supply	1,705		
Attributed CO_2 emissions to electricity supply	641		
Sub total (B)	*-71,128*	*Sub total (B)*	*-71,128*
Stocks Added (via production)		Flows Added (via production)	
Attributed and direct CO_2 emissions allocated to SAF	-40,543	Direct CO_2 emissions	23,867
Attributed and direct CO_2 emissions allocated to LPG	-3,859		
Attributed and direct CO_2 emissions allocated to naphtha	-2,859		
Sub total (C)	*-47,261*	*Sub total (C)*	*23,867*
Stocks Subtracted		Flows Subtracted	
Attributed CO_2 emissions to soybean oil used for production	-73,474	SAF sold to customer	-40,543
Attributed CO_2 emissions to natural gas used for production	1,705		
Attributed CO_2 emissions to electricity used for production	641		
SAF sold to customer	-40,543		
Sub total (D)	*-111,671*	*Sub total (D)*	*-40,543*
Ending Stocks Balance (A+B+C-D)	*-6,718*	*Ending Flows Balance (A+B+C-D)*	*-6,718*

For each accounting period, such as the three-month period of the case study, the ledger is kept in balance by the relationship that changes in the balance of CO_2 emissions stocks equals the net flow of CO_2 emissions entering and existing the entity's boundaries. Note

that the ending balance of -6,718 tons CO_2 represents the emissions allocated to the LPG and naphtha products remaining in inventory at the end of the accounting period. The SAF product was sold and thus transferred from the SAF producer's ledger to the customer's ledger.

Ledger perspective derived from E-Ledgers concepts: The E-Ledgers accounting system is organized on the basis of assets and liabilities as compared to the stocks and flows organization discussed above. In the E-Ledgers system, carbon removals are recorded as assets, and all transactions affecting CO_2 emissions are recorded as liabilities. The system included double-entry bookkeeping of transfers from one ledger to another across a supply chain, with single-entry bookkeeping of transactions within each entity's ledger. The ledger does not include data on carbon content of materials, fuels or products.

A summary of the SAF production case study entity-level transactions, in the format of assets and liabilities derived from E-ledger concepts,[15] is shown in Table 2.

Table 2. Summary of transactions in format derived from E-Ledgers organization of assets and liabilities: CO_2 emissions ledger with single-entry bookkeeping

a) Crude oil refiner ledger transactions in E-Ledger format

Transfer of raw materials and energy inputs

CO_2 Emissions Assets (tCO_2)		CO_2 Emissions Liabilities (tCO_2)	
		Attributed CO_2 emissions to natural gas transferred in	7,154
		Attributed CO_2 emissions to Bakken Crude transferred in	219,032
		Sub-Total	*226,186*
Net CO_2 Balance			*226,186*

Conventional jet fuel production

CO_2 Emissions Assets (tCO_2)		CO_2 Emissions Liabilities (tCO_2)	
		Attributed CO_2 emissions to natural gas transferred in	7,154
		Attributed CO_2 emissions to Bakken Crude transferred in	219,032
		Direct CO_2 Emissions Generated	250,220
		Sub-Total	*476,406*
Net CO_2 Balance			*476,406*
		Jet fuel product allocation factor	2.67%
Net CO_2 allocated to jet fuel			*12,741*

b) SAF producer ledger transactions in E-Ledger format

Transfer of raw materials and energy inputs

CO_2 Emissions Assets (tCO_2)		CO_2 Emissions Liabilities (tCO_2)	
Net CO_2 removals attributed to soybean oil transferred in	73,474	Attributed CO_2 emissions to electricity transferred in	641
		Attributed CO_2 emissions to natural gas transferred in	1,705
Sub-Total	*73,474*	*Sub-Total*	*2,346*
Net CO_2 Balance	*71,128*		

SAF Production

CO_2 Emissions Assets (tCO_2)		CO_2 Emissions Liabilities (tCO_2)	
Net CO_2 removals attributed to soybean oil transferred in	73,474	Attributed CO_2 emissions to electricity transferred in	641
		Attributed CO_2 emissions to natural gas transferred in	1,705
		Direct CO_2 Emissions	23,867
Sub-Total	*73,474*	*Sub-Total*	*26,213*
Net CO_2 Balance	*47,261*		
SAF product allocation factor	85.8%		
Net CO_2 allocated to SAF	*40,543*		

c) Airline customer ledger transactions in E-ledger format

Transfer of jet fuels and use

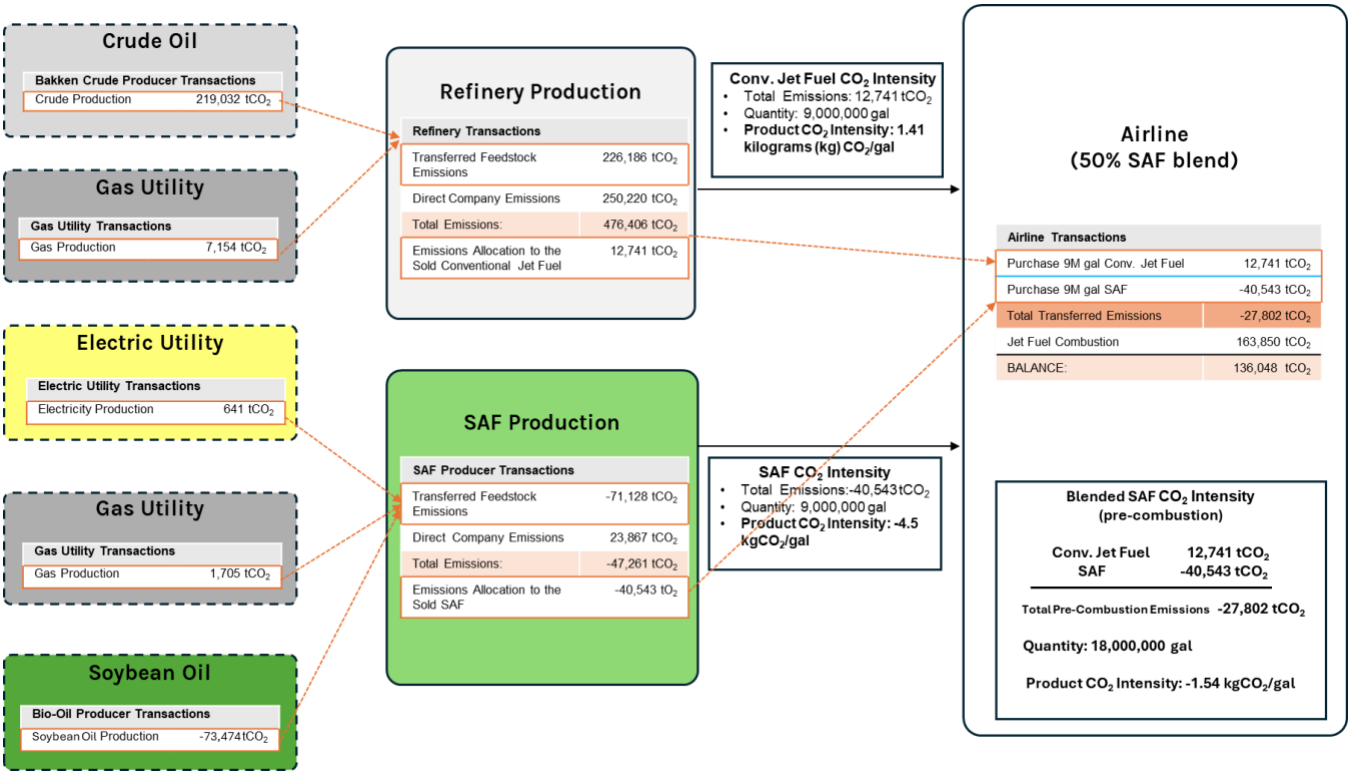
CO_2 Emissions Assets (tCO_2)		CO_2 Emissions Liabilities (tCO_2)	
Net CO_2 removals attributed to SAF transferred in	40,543	Attributed CO_2 emissions to conventional jet fuel transferred in	12,741
Net CO_2 balance	27,802		
		Jet Fuel Combustion	163,850
Net CO_2 balance			*136,048*

In the E-Ledgers format, the net negative estimate of CO_2 emissions associated with the biogenic soybean oil is recorded as an asset, reflecting that its value reflects the net effect of atmospheric removal of CO_2 in the soybean growing process. Table 2 also shows the transfers of CO_2 emissions from the ledgers of the crude oil refiner and the SAF producer to the ledger of the airline. In this instance, it is assumed that the SAF fuel blend is combusted within the same accounting period. The ledger data is shown for entity-level totals only.

Derivation of product CO_2 emissions intensity values would require matching the CO_2 emissions estimates with production estimates over the same accounting period.

CO_2 emissions balance perspective: Another view of the ledger transactions is shown in Figure 3. This illustration identifies all of the sources of CO_2 emissions at each stage of the SAF production process.

Figure 3. All streams of CO_2 emissions derived from ledger transactions



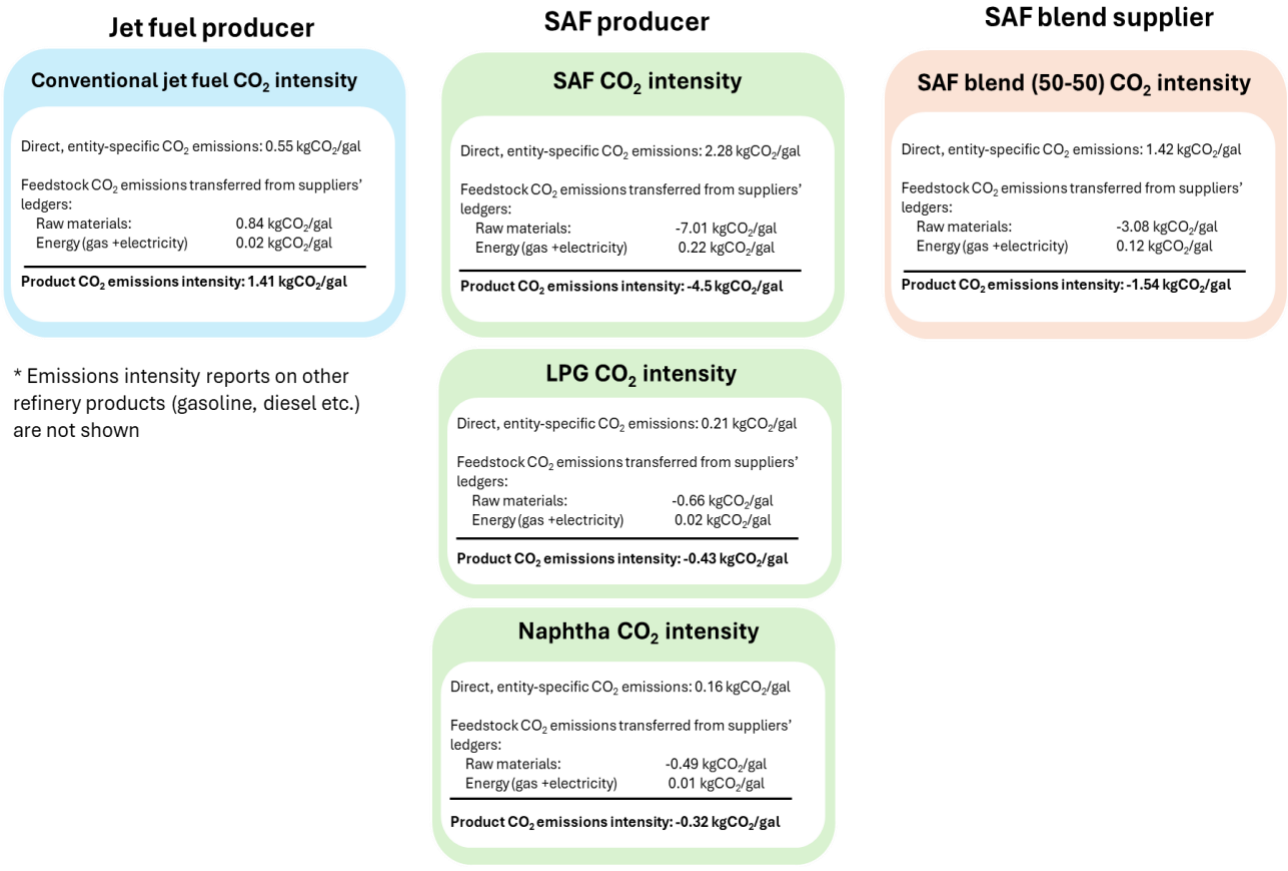
Source: Sesame Sustainability.

The figure provides a complete picture of the CO_2 emissions attributed to suppliers and transferred from their ledgers to the SAF producer's ledger along with supply chain materials, direct CO_2 emissions from SAF production, allocation of CO_2 emissions among products, and CO_2 emissions transferred to the ledgers of customers along with final products. The figure also shows the resulting CO_2 emissions from the 50-50 SAF blend and product CO_2 emissions intensity.

Product CO_2 emissions intensity and entity total emissions reports—management and policymaker perspectives: The ledger is agnostic with respect to reporting formats and applications. Figure 4 and Table 3, described below, illustrate several different reporting formats for the CO_2 emissions accounting data drawn from the stocks and flows ledger summarized in Table 1 (with details in Appendix B).

Product CO_2 emissions intensity reports: Figure 4 illustrates a sample report on product CO_2 emissions intensities that could be provided to management and to customers. The product CO_2 emissions intensity reports include total CO_2 emissions as well as a disaggregation of the total among attributed CO_2 emissions from the supply chain and direct CO_2 emissions intensities from production of final products -- conventional jet fuel, SAF (and its byproducts), and the resulting SAF blend. The resulting product CO_2 emission intensities show that a 50-50 SAF blend reduces the CO_2 emissions intensity by 209% relative to conventional jet fuel.

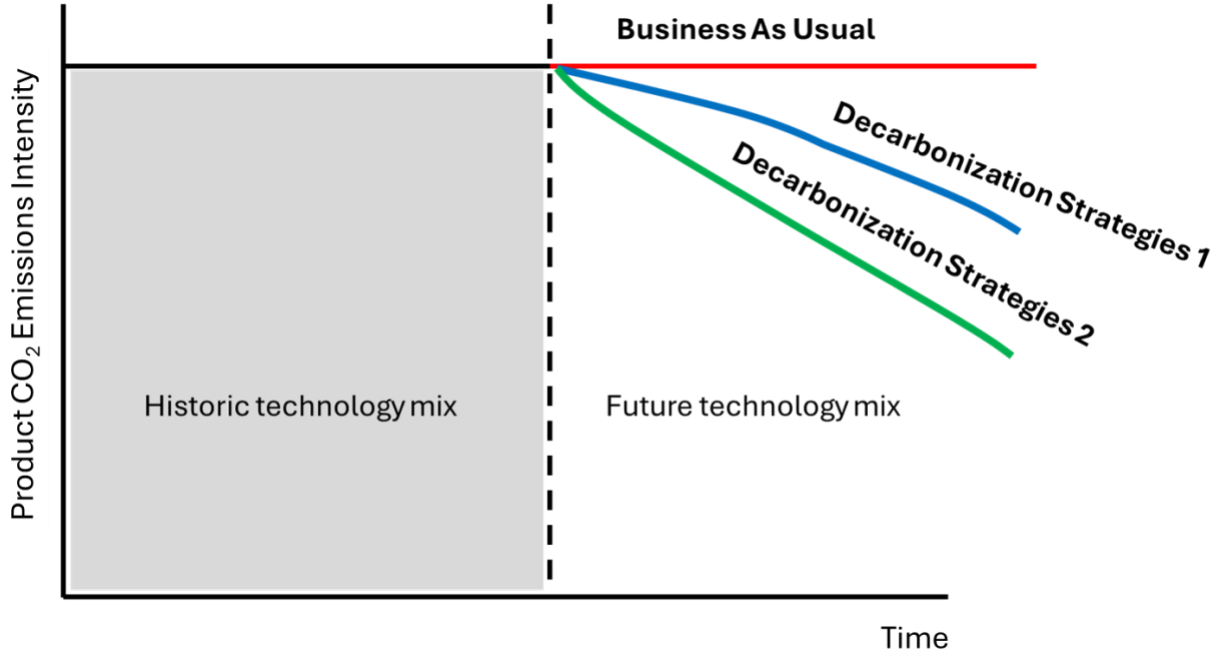
Figure 4. Product CO_2 emissions intensity reports derived from the ledger



Source: Sesame Sustainability.

Complete and transparent reports of CO_2 emissions intensity provide important information to both the SAF producer as well as the airline customer. For the airline customer, the product CO_2 emissions intensity report provides the data needed to support its own strategic planning and marketing objectives, including information to guide decisions on its willingness to pay for lower carbon differentiated products. For the SAF producer, the product CO_2 emissions intensity provides a KPI to identify and assess opportunities to reduce product CO_2 emissions intensity through the implementation of additional decarbonization strategies. Decarbonization strategies could include, for example, purchase of lower CO_2 emissions intensity feedstocks or electricity, or abatement of CO_2 emissions generated from the SAF production process. The use of product CO_2 emission intensity estimates could allow for comparisons among alternative decarbonization strategies as illustrated in Figure 5.

Figure 5. Use of product CO_2 emissions intensity metric to compare alternative decarbonization investment strategies



Source: EFI Foundation

Figure 5 is a conceptual illustration of how the scale and pace of specific decarbonization actions can ultimately be reflected in lower product CO_2 emission intensity levels. This analysis can inform the investability of capital investment alternatives. The investments in lower product CO_2 emissions intensity could be motivated by business decisions to improve competitive position in a carbon differentiated product market. Alternatively, investments could be required to find the most cost effective decarbonization strategy to

meet a mandated product carbon intensity standard (PCIS) within a specified timeframe. The ledger data is agnostic as to the purpose of the analysis.

Entity-Level CO_2 Emissions Reports: Table 3 provides a summary table on total entity-level emissions. The table is organized in three parts. The first part summarizes total direct CO_2 emissions and the allocation of direct emissions among products.

Table 3. SAF producer's entity-level and product-level total CO_2 emissions report

	Emissions category	Value	Allocation rate
Direct CO_2 emissions	Direct CO_2 emissions allocated to **SAF** product	20,474 tCO_2	85.8%
	Direct CO_2 emissions allocated to **LPG** product	1,949 tCO_2	8.2%
	Direct CO_2 emissions allocated to **naphtha** product	1,444 tCO_2	6.0%
	*Total **entity-level** direct CO_2 emissions*	*23,867 tCO_2*	*100%*
Attributed CO_2 emissions	Attributed CO_2 emissions allocated to **SAF** product	-61,017 tCO_2	85.8%
	Attributed CO_2 emissions allocated to **LPG** product	-5,808 tCO_2	8.2%
	Attributed CO_2 emissions allocated to **naphtha** product	-4,303 tCO_2	6.0%
	*Total **entity-level** attributed CO_2 emissions*	*-71,128 tCO_2*	*100%*
Total CO_2 emissions (direct CO_2 plus attributed CO_2 emissions)	Total CO_2 emissions allocated to **SAF** product	*-40,543 tCO_2*	85.8%
	Total CO_2 emissions allocated to **LPG** product	*-3,859 tCO_2*	8.2%
	Total CO_2 emissions allocated to **naphtha** product	*-2,859 tCO_2*	6.0%
	*Total **entity-level** CO_2 emissions*	*-47,261 tCO_2*	*100%*

The second section of the report summarizes the total attributed CO_2 emissions that were transferred to the SAF producer's ledger from supplier ledgers and how these were subsequently allocated to products. The third section simply captures total CO_2 emissions.

The ability to report both total CO_2 emissions as well as the disaggregation of those emissions across the supply chain prevents any inadvertent double-counting CO_2 emissions. It also provides a complete and transparent audit trail to support third-party verification to ensure completeness and protect against manipulation of the allocations.

Concepts Toward a Rule Book to Support Ledger-Based Accounting

The rule book specifies the methodologies for establishing the values of the transactions to be recorded in the ledger. The ledger provides the framework for recording transactions; the rule book determines the level of CO_2 emissions to be recorded.

A pragmatic approach will be required for rule book development. The initial set of priorities for rules will need to focus on the methodological issues that are most impactful for entity-level and product CO_2 emissions intensity reporting. The methodologies themselves may in some cases initially rely upon accepted approximations for purposes of accounting. The scope and quality of the rule book will evolve over time as experience is gained in implementation. Several high priority rule book issues are highlighted below. Examples of how accounting for these issues in the ledger will be included in the case studies listed earlier in Box 2.

Product-level CO_2 emissions allocation formulas: The single most essential rule is the methodology for allocation of total CO_2 emissions among products in an entity with multiple product lines. The combination of attributed CO_2 emissions transferred in from suppliers' ledgers and direct CO_2 emissions within the entity should be allocated across product lines based on causal logic that is defined in the rule book and applied to carbon mass and energy balance data.

Depending upon the nature of the feedstock materials and products and the processes of transformation, the allocation rules could be based on either mass or energy. In the SAF-HEFA case study summarized in the previous section, CO_2 emissions were allocated based on energy content of the three product streams—SAF, LPG, and naphtha. For a commodity product such as steel, a mass-based allocation formula would be more appropriate. Certain other minor sources of CO_2 emissions, such as those associated with administrative or overhead activities, could be allocated in a similar manner, or may be allocated based on dollar value of the products. In any event, the rule book needs to be rigorous in defining the allocation methodology and emphasize consistency in its application.

CO_2 emissions abatement: CO_2 emissions abatement captures CO_2 generated in the production process within the entity's boundaries and otherwise emitted into the atmosphere. The abated CO_2 emissions are then isolated from the environment via some form of storage or used in an inert form in a product. The rule book will need to proscribe how the entity records on the ledger the data and relationships among the gross level of CO_2 emissions *generated* within the entity prior to abatement, the level of CO_2 emissions

abated, and the *net CO2 emissions released* to the atmosphere within the same time period. The rule book also would need to specify how the value of the CO_2 emissions abatement would be adjusted to reflect any increased CO_2 emissions incurred in the abatement process. Finally, the level of the CO_2 emissions abatement would need to reflect any leakage from storage that might occur within the same time period as CO_2 emissions are abated.

The final estimated value of the CO_2 emissions abatement can then be applied in two ways depending upon its use: if the CO_2 abatement is intended to reduce both the reported net total direct CO_2 emissions and the CO_2 emissions allocated to product-level CO_2 emissions intensity, the abatement can be recorded as a contra (i.e. negative) entry to both stocks and flows on the ledger. Alternatively, the entity might seek to sell or trade the CO_2 emissions abatement as a CO_2 emissions reduction credit that could be transferred to the ledger of the 3rd party purchaser. In this case the CO_2 emissions abatement would be removed as a contra entry to CO_2 emissions stocks and flows as its value is transferred from the entity's ledger to the recipient's ledger. This will avoid double-counting of the abatement by the two entities in the transaction.

CO_2 removals: These include removal of legacy CO_2 emissions already residing in the atmosphere; they also can include removal of CO_2 emissions that have been absorbed into marine or terrestrial environments that have the potential for re-release to the atmosphere.[g] The method of removal could include natural, technological, or technology-assisted natural means). There are several major methodological issues to be addressed in the rule book for determining the estimated CO_2 emissions benefit from removals: (1) the permanence of the removal (i.e., the length of time that the removal is isolated from the environment), (2) the methodology for determining the net value of the CO_2 removal (after consideration of CO_2 emissions generated by the removal process), and (3) potential leakage of CO_2 while it is in storage and how it should be estimated. The removals can be recorded on the ledger as they occur, matching the recording of new direct emissions from the entity within the same accounting period. If there is leakage of the removal, the estimated rate of leakage can be applied to arrive at an estimate of the net removal and recorded concurrently. In the ledger, the CO_2 removal transactions would be recorded as a contra (i.e., negative) entry to both carbon stocks and flows.[h] This would reduce the entity-

[g] For purposes of this discussion, CO_2 emissions avoidances are not included. As their name implies, avoidances are not reductions from current emissions, but actions to prevent future emissions. There currently is significant disagreement on the basis for including avoidances in a CO_2 emissions accounting system as well as the methodologies for estimating their value for carbon accounting purposes.

[h] In the E-Ledgers accounting ledger, which is organized by assets and liabilities rather than stocks and flows, CO_2 removals would be recorded as an asset that subsequently could be netted against the entity's liabilities.

level total CO_2 emissions as well as the allocations to product-level CO_2 emission intensities.

Environmental attributes of electricity: Environmental attributes can include contracts for carbon-free electricity obtained through bilateral power purchase agreements (PPAs) or purchases of Renewable Energy Certificates (RECs). The ledger allows for separate recording of the CO_2 emissions attributed to the delivered electricity and any environmental attribute held by the entity that is not reflected in the attributed CO_2 emissions of the actual delivered electricity. The rule book will need to define the methodologies for developing estimates for both.

The CO_2 emissions of the electricity grid providing power to an entity typically cannot be uniquely assigned to a particular generation source or a particular customer at any specific time. Some form of grid averaging will be needed, most likely derived from modeling. In the SAF case study described earlier, for example, the CO_2 emissions attributed to the grid-based electricity supply was estimated based upon the GREET model "wall outlet" average for the SAF production facility located in Montana. The estimation process can be improved over time with greater granularity in location and time matching of the grid averages with the other transactions that underpin product CO_2 emissions intensity.

The challenge becomes more complex for the CO_2 emissions accounting of the environmental attributes of specific individual generation sources separately from grid average CO_2 emissions. There are several issues to be addressed, such as additionality of the carbon free electricity generation associated with the attribute and its relationship to the grid average CO_2 emissions, as well as time matching of the attribute to the time period of the entity's CO_2 emissions accounting. These will require development of methodologies to provide an accepted approximation for purposes of product- and entity-level CO_2 emissions accounting. An entity's purchase of carbon free electricity attributes from an existing carbon free generation source on the grid, for example, represents a transfer from the generator to the purchasing entity, with no net reduction of CO_2 emissions to the atmosphere. It leaves the grid with what is characterized as "null power,[i]" stripped of any CO_2 emissions attributes, that in turn will impact the grid average CO_2 emissions intensity. If, on the other hand, the attribute is associated with an addition of new carbon free generation to the grid, the rules for recording the value of the attribute on the ledger

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Also, for purposes of balance sheet reporting, the estimated net cumulative benefit of the CO_2 removal could be capitalized over its expected lifetime.

[i] "Null power" refers to the residual electricity supply that remains carbon free but has been stripped of its environmental attribute. The transfer of the environmental attribute power impacts calculated average CO_2 emissions intensity of the grid where the generator is connected, creating a ripple effect on other customers who are not aware of, or party to, the transaction. It also could lead to double counting of the attribute.

may be simpler and avoid impacting grid averages. Longer term, movement toward a carbon-free grid would diminish ambiguities in the rules for CO_2 emissions accounting.

Examples of other issues that will likely arise in the process of rule book development include:

- **CO_2 emissions attributed to the use of fixed property, plant and equipment (PPE):** Rules will be required to determine the accounting for CO_2 emissions associated with the fabrication of processing equipment used by the entity within its boundaries. For example, the E-Ledgers and ICCA systems capitalize all CO_2 emissions attributed to the manufacture of PPE as a balance sheet liability and amortizes the liability over time as an annual charge to the entity's total CO_2 emissions and product CO_2 emissions intensities. The rule book methodology also may need to distinguish between PPE in place at the beginning point of the ledger and PPE that is newly acquired and deployed during the course of the accounting period, as historical information on PPE that has been in service for some time may not be readily available.
- **CO_2 emissions from transport of raw materials and finished products:** The rules for estimating CO_2 emissions from transport will vary depending upon the means of transport – air, rail, barge or truck. Rules for recording the transport CO_2 emissions will need to be based on ownership of transportation assets and terms and conditions in contracts for 3rd party transportation services. If a 3rd party provides transport services, the CO_2 emissions should be recorded on its ledger. The transporter can then transfer the CO_2 emissions to the ledger of the contracting entity. Ultimately transport-related CO_2 emissions up to the point of production ultimately will be transferred to the producing entity's ledger and allocated to product-level CO_2 emission intensities. CO_2 emissions for transport of finished products will be the responsibility of the seller or buyer depending upon the terms of the sales contract.
- **Refinement of accounting boundaries:** The boundaries for ledger design are based on the general principle of ownership and control of operation, assuming that, on a first-order basis, the boundaries for the CO_2 emissions ledger would be most likely aligned with the entity's financial reporting boundaries. There could be a need for further delineation of the boundaries to address issues such as separate, unrelated activities occurring within the entity's boundaries or an entity's equity stake in an activity outside the boundary.

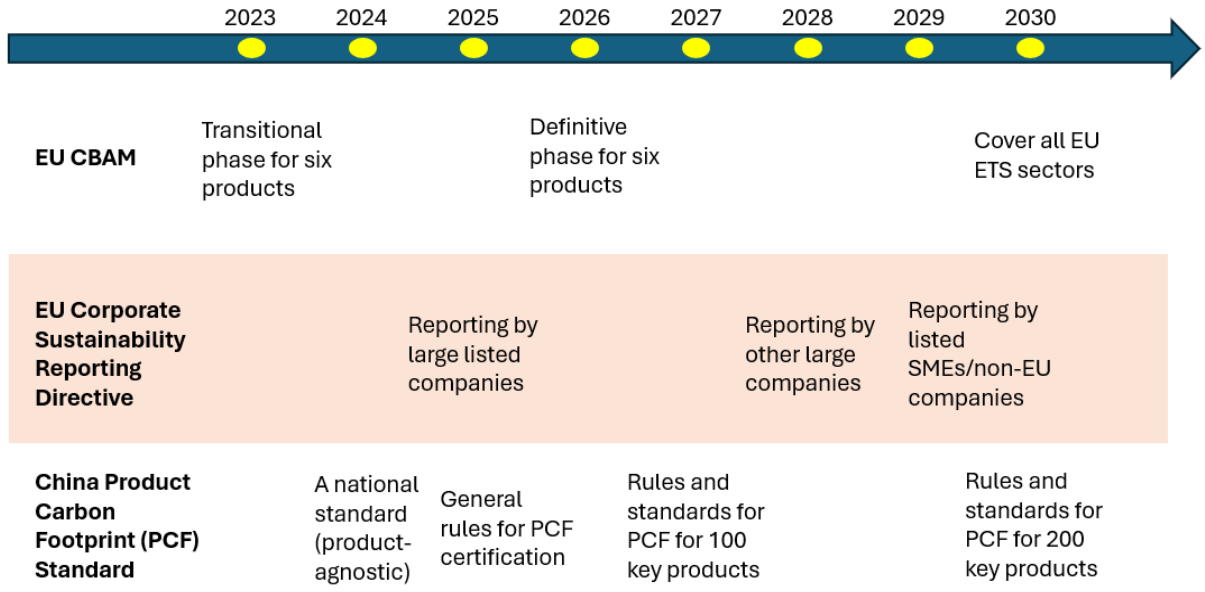
Implementation of a Ledger-Based Integrated Product- and Entity-Level CO2 Emissions Accounting System

Establishing a path forward for carbon accounting requires an effective regime to guide agreement and provide oversight on how the system is designed and implemented.

Climate action has spurred the development of multiple frameworks advanced by private, non-governmental organizations that help companies and governments count and report GHG emissions and removals. These frameworks now have significant influence on the landscape of compliance reporting in support of voluntary corporate goals, voluntary carbon markets, and national climate policy directives.

Emerging international policy developments are raising the stakes, creating the need for improved and standardized entity-level and product-specific CO_2 emissions accounting standards. Following a two-year transitional phase, the EU CBAM is scheduled to enter full implementation in 2026. China issued a national product carbon footprint (PCF) standard in 2024 and plans to apply it to establish PCF standards for key products in the coming years (Figure 6).

Figure 6. Implementation milestones for new international policies affecting product CO_2 emissions intensity standards



Note: SME = small and medium-sized enterprises; ETS = emissions trading system. Source: EFI Foundation.

Opportunities and challenges to harmonization: There are growing calls for harmonization of the current and emerging frameworks. These include a recommendation by the European Commission (EC), the inclusion of carbon accounting on the agenda for the upcoming UN Framework Convention on Climate Change (UNFCCC) Conference of the

Parties (COP30), and the 2025 B7 Communique.[j] Government action to initiate a harmonization agenda could be adopted in one or more international forums, including COP30, the G7, the G20, or the Clean Energy Ministerial (CEM).

The challenge for harmonization is that it should go well beyond simply seeking commonality among current reporting guidelines.

- Current frameworks, such as the GHGP Corporate Accounting and Reporting Standard, the GHGP Product Standard, and ISO 14067,[k] are purpose-built to serve specific goals, primarily assisting companies in identifying and inventorying their CO_2 emissions.[l] They lack clear rules for integrating CO_2 emissions data across supply chains without gaps or duplication, reconciling CO_2 emissions with carbon content in materials and products, allocating CO_2 emissions among multiproduct entities, and integrating product-level CO_2 emissions intensities into entity-level CO_2 total emissions without duplication or gaps. In September 2025 the GHG Protocol and ISO announced a strategic partnership to harmonize their existing portfolios of GHG standards.[16] An accompanying blog post by the Chair of the GHGP Steering Committee noted that the current fragmented frameworks have "little of which are aggregable or comparable."[17] Integration of product- and entity-level CO_2 emissions accounting will be a formidable challenge.

New initiatives, such as CBAM and China's evolving national standards will add to the challenges.

- Under CBAM, importers of the six listed commodities will need to obtain certificates for their product CO_2 emissions intensity. The EC will determine the number of certificates for each product based on country-specific estimates of CO_2 emissions intensity for imports from that country, with certificate prices tied to the carbon price in the EU-ETS market.
- The framework for establishing Chinese PCFs appears to be largely based on ISO 14067.[18] As noted above, however, the current ISO standard does not support integration of product CO_2 emissions intensity measures with entity-total CO_2 emissions reports. In addition, the PCF values would reflect data from different time periods, as the standard takes a life cycle approach that encompasses the entire life span of a product—from raw material acquisition to use and end-of-life treatment.

[j] The B7 is the voluntary organization of national business associations supporting the G7 process.
[k] ISO 14067 is an international standard specifying the requirements and guidelines for quantifying and reporting the carbon footprint of a product.
[l] See Appendix A for a listing of over a dozen of the current emissions reporting frameworks.

Private-sector self-organizing for action: Entities motivated by global market forces have incentive to take the lead in setting fair, transparent, and verifiable rules of the road for trade in carbon-differentiated products and processes. The October 2025 launch of *Carbon Measures*, a new coalition initially comprised of 19 global companies spanning multiple industry sectors, provides the opportunity to begin the process of moving toward a uniform CO_2 emissions accounting system. The goal of Carbon Measures is to establish a standardized framework for measuring carbon emissions across products and supply chains, addressing issues such as double-counting and improving transparency in carbon accounting.[19] As noted by the CEO of the new endeavor, "Carbon Measures wants to create a system that will unleash markets and competition, unlocking investment and accelerating the pace of emissions reduction – ultimately driving the kind of enduring change the world demands."[20]

The initiative will seek to accomplish this objective through development of a ledger-based carbon accounting framework modeled on financial reporting standards. This approach will help track emissions as products move through supply chains, ensuring that carbon data is attached to products, similar to how price or weight is recorded. The initial focus will be on high-emission industrial products, including electricity, fuels, steel, concrete and chemicals.[m] This effort could initiate process that ultimately could evolve into a public-private partnership.[n]

Transition issues will need to be considered carefully. In 2023, 97% of the S&P 500 companies reported entity-level CO_2 and other GHG emissions to the Carbon Disclosure Project (CDP) using the GHG Protocol Corporate Accounting and Reporting Standard.[21]

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[m] The *Carbon Measures* agenda likely will address many of the issues discussed in this paper. The work of EFI Foundation and Carbon Measures, however, remain separate and independent, and Carbon Measures has not expressed any opinion on the material in this report.

[n] The evolution of financial accounting offers a model for the evolution of a public-private partnership, although on a much different timescale. In the U.S., balance sheet financial accounting first emerged in the railroad industry in the late 19th century to facilitate raising debt capital. Income statements later evolved to support widespread public participation in equity markets. After the 1929 stock market crash revealed the limits of fragmented practices, the federal government intervened to establish a governance process for uniform standards setting. Governance for financial accounting ultimately evolved into a public-private partnership: standard-setting by the independent non-governmental Financial Accounting Standards Board, implementation by the Securities and Exchange Commission for U.S publicly traded companies, and uniform application through third-party auditing. A similar public-private partnership has emerged internationally, with development of financial accounting standards by the non-governmental International Accounting Standards Board and implementation through EU mandates for companies listed on European stock exchanges.

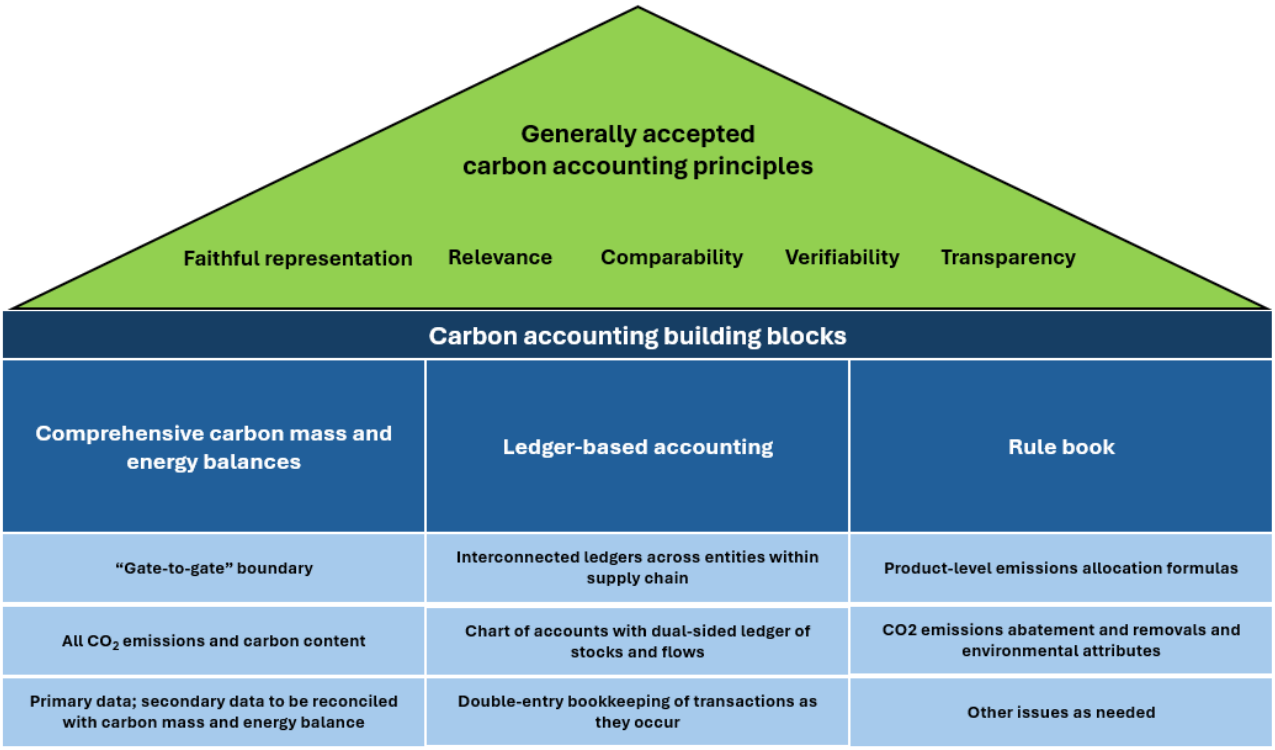
The United States' role: Several analyses indicate that U.S. industry as a whole is more energy efficient and uses more carbon-efficient energy to produce the same value of product as international competitors.[22] U.S.-based companies competing in global markets could be at risk for unfair trading practices, however, if the process for setting carbon accounting standards and reporting favors the entities operating in the home companies crafting those rules. The U.S. government has a vital interest in international standards-setting, trade, and competitiveness. The Department of Commerce, working though the National Institutes of Standards and Technology and the International Trade Administration, could play an important role in ensuring that emerging international carbon accounting standards are technically grounded, fair, and verifiable.

Conclusion

The establishment of a comprehensive CO_2 emissions accounting system—including principles, standards, a rule book, and governance—can be informed by financial accounting principles and supported by established engineering fundamentals. Implementation of the system will support the establishment of product CO_2 emissions intensity metrics that can be derived from and integrated with entity-level total CO_2 emissions. These metrics will allow buyers and sellers to engage in carbon-differentiated market transactions and unlock new investments in lower-carbon solutions while meeting growing energy demand.

This paper describes a model comprehensive CO_2 emissions accounting system, consistent with well-established and generally accepted financial accounting principles, built on a ledger-based accounting framework organized by carbon stocks and flows, and drawing from a variety of accounting concepts in academic literature. This system is summarized in Figure 7.

Figure 7. Building blocks of a comprehensive model CO_2 emissions accounting system



Source: EFI Foundation.

The model accounting system has been demonstrated through several hypothetical case studies. One of these cases, sustainable aviation fuel, is summarized in this paper. Further details of this and other case studies will be published separately.

The comprehensive model CO_2 emissions accounting system described in this report is also applicable to other greenhouse gases. Implementation can begin with CO_2 emissions and expand to include other GHGs over time. Market opportunities for carbon-differentiated products, along with emerging policies targeting product-based CO_2 emissions intensity, underscore the urgent need to establish a widely accepted carbon accounting system, while acknowledging that it will evolve over time. What is needed now is to organize the process that can guide implementation.

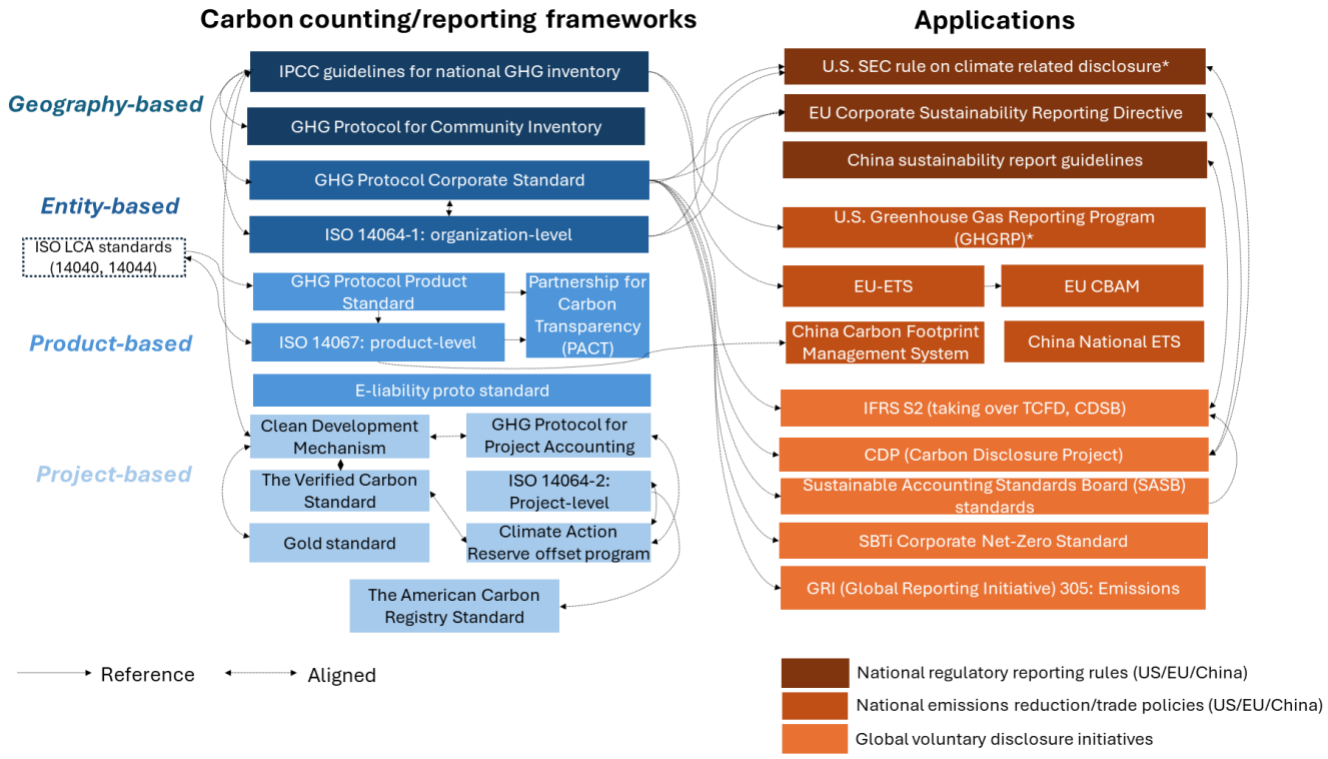
Appendix A. The Current Landscape of Carbon Reporting Frameworks

The current landscape of carbon counting and reporting frameworks includes more than a dozen sets of guidelines, with the GHG Protocol Corporate Accounting and Reporting Standard being the primary one. Many were specially designed to serve a predefined public policy mandate or a voluntary corporate climate commitment.

These frameworks span geography-based (i.e., national inventories), entity-wide, product-based, and project-focused reporting, depending upon the purpose and objectives of the end use. Frameworks that focus on entity-level reporting are the most widely used, while those supporting product-based life cycle analysis are less commonly used in national policies or global voluntary initiatives.

The connections between these various frameworks and the objectives they serve are illustrated in Figure A1.

Figure A1. Carbon counting and reporting frameworks and their applications



** Notes: The U.S. Securities and Exchange Commission (SEC) adopted climate-related disclosure rules in March 2024; however, the rules were challenged in court, and the SEC ended its defense of them in March 2025. The U.S. Environmental Protection Agency in September 2025 proposed to eliminate a substantial portion of the Greenhouse Gas Reporting Program (GHGRP). Source: EFI Foundation.*

Appendix B. Description of Detailed Ledger Entries

This appendix describes the detailed set of entries to the ledger supporting the summary CO_2 ledger report described in Figure 3. As described in the report, the ledger is a dual-sided chart of accounts of all stocks and flows of all forms of carbon entering, processed within, and exiting the entity's boundaries.

For ease of discussion, the ledger entries are divided into two figures. Figure B1 shows the transfer of carbon accounting data from suppliers' ledgers to the entity's ledger and the carbon accounting associated with the SAF production process. The second figure, B2, shows the allocation of the entity's production process to the three products—SAF, LPG, and naphtha—and subsequent transfer of SAF from the entity's ledger to the customer's ledger.

Figure B1 illustrates the set of transactions recorded in the SAF producer's ledger from the point of transfer of feedstocks from suppliers' ledgers through the SAF production process. The SAF producer's ledger assumes that each supplier has its own complete ledger for the feedstocks being supplied to the SAF producer, with CO_2 transactions recorded only once, at the source, and then transferred from the suppliers' ledgers to the SAF producer's ledger.

The first set of transactions in the ledger show the transfer of ledger data (CO_2 emissions attributed to the development of the feedstocks as well as their physical carbon content) of the feedstocks from the suppliers' ledgers to the SAF producer's ledger. The next set of transactions recorded in the ledger show the processing of the feedstock materials in the SAF conversion process, including the conversion of the carbon content in fuels and feedstock to direct CO_2 emissions. All transactions are recorded in double-entry bookkeeping.

The conversion process yields three products: SAF, naphtha, and liquefied petroleum gas (LPG). The ledger shows the total amount of CO_2 emissions attributed to the product slate prior to allocation. Note that all data in the ledger (both emissions and carbon content) are recorded as tons of carbon (tC) to facilitate conversions of carbon content to CO_2 emissions in the same units.

Figure B1. Detailed Ledger entries for transfer of feedstock CO_2 emissions attributed to suppliers from their ledgers to the SAF producer's ledger, and CO_2 emissions generated by the conversion of feedstocks to products (SAF, LPG and naphtha)

Accounting period: One calendar quarter.
All units in tons carbon (tC).

SAF producer's ledger

Phase 1. Transfer feedstock emissions and supporting carbon content from suppliers' ledgers to the SAF producer's ledger

Carbon transferred in from soybean oil supplier

Account	Debit	Credit
Feedstock Emissions (Soybean Oil)	(20,015.8)*	
Feedstock Emissions Transferred In	-	(20,015.8)
Feedstock Carbon Content (Soybean Oil)	27,702.7	
Feedstock Carbon Content Transferred In		27,702.7
Sum	*7,687*	*7,687*

**Negative emissions resulting from the capture and storage of biogenic carbon during soybean production*

Carbon transferred in from natural gas supplier

Account	Debit	Credit
Feedstock Fuels Emissions (Natural Gas)	504.8	
Feedstock Emissions Transferred In	-	504.8
Feedstock Fuels Carbon Content (Natural Gas)	5,101.9	
Feedstock Carbon Content Transferred In	-	5,101.9
Sum	*5,606.7*	*5,606.7*

Carbon transferred in from electricity supplier

Account	Debit	Credit
Electricity Emissions	176	
Electricity Emissions Transferred In		176
Sum	*176*	*176*

Phase 2. Conversion of feedstocks to products and direct emissions

Moving feedstocks from inventory to production process

Account	Debit	Credit
Feedstock Emissions (Soybean Oil) in Work-In-Process**	(20,015.8)	
Feedstock Emissions (Soybean Oil)		(20,015.8)
Feedstock Fuels Emissions (Natural Gas) in Work-In-Process	504.8	
Feedstock Fuels Emissions (Natural Gas)		504.8
Electricity Emissions in Work-In-Process	176	
Electricity Emissions		176
Feedstock Carbon Content (Soybean Oil) in Work-In-Process	26,287.8	
Feedstock Carbon Content (Soybean Oil)		26,287.8
Sum	*6,952.8*	*6,952.8*

***Work-In-Process refers to partially completed products. Carbon remains in Work-In-Process account until the production is completed.*

Direct emissions from production

Account	Debit	Credit
Direct Entity Emissions Work-In-Process	6,516.9	
Feedstock Fuels Carbon Content (Natural Gas)		5,101.9
Feedstock Carbon Content (Soybean Oil)		1,415
Sum	*6,516.9*	*6,516.9*

Note: Each value in this figure represents the total of all carbon forms—CO_2, CH_4, CO, VOCs, and carbon content. The values are aggregated for presentation purposes, while the underlying ledger maintains disaggregated data for each carbon form. The ledger expresses all entries in tons of carbon, serving as a common unit to balance all carbon forms. Source: EFI Foundation and Sesame Sustainability.

Figure B2 shows the allocation of CO_2 emissions among the products, and transfer of the product-based CO2 emissions to the airline customer ledger.

Figure B2. Detailed Ledger entries for the allocation of attributed and direct CO_2 emissions to products and transfer to the customer's ledger with products sold

Accounting period: One calendar quarter.
All units in tons carbon (tC).

SAF producer's ledger

Phase 3. Allocation of entity-level carbon to finished product inventory

Carbon allocated to SAF inventory

Account	Debit	Credit
Direct Entity Emissions Allocated to SAF	5,595.3	
Direct Entity Emissions Work-In-Process		5,595.3
Feedstock Emissions Allocated to SAF	(17,185.3)	
Feedstock Emissions (Soybean Oil) in Work-In-Process		(17,185.3)
Feedstock Fuels Emissions Allocated to SAF	433.4	
Feedstock Fuels Emissions in Work-In-Process	-	433.4
Electricity Emissions Allocated to SAF	151.1	
Electricity Emissions in Work-In-Process	-	151.1
Feedstock Carbon Content Allocated to SAF	22,366	
Feedstock Carbon Content in Work-In-Process	-	22,366
Sum	*11,360.5*	*11,360.5*

Carbon allocated to naphtha inventory

Account	Debit	Credit
Direct Entity Emissions Allocated to Naphtha	393.4	
Direct Entity Emissions Work-In-Process		393.4
Feedstock Emissions Allocated to Naphtha	(1,208.2)	
Feedstock Emissions (Soybean Oil) in Work-In-Process		(1,208.2)
Feedstock Fuels Emissions Allocated to Naphtha	30.5	
Feedstock Fuels Emissions in Work-In-Process		30.5
Electricity Emissions Allocated to Naphtha	10.6	
Electricity Emissions in Work-In-Process		10.6
Feedstock Carbon Content Allocated to Naphtha	1,799.2	
Feedstock Carbon Content in Work-In-Process		1,799.2
Sum	*1,025.5*	*1,025.5*

Carbon allocated to LPG inventory

Account	Debit	Credit
Direct Entity Emissions Allocated to LPG	528.2	
Direct Entity Emissions Work-In-Process		528.2
Feedstock Emissions Allocated to LPG	(1,622.3)	
Feedstock Emissions (Soybean Oil) in Work-In-Process		(1,622.3)
Feedstock Fuels Emissions Allocated to LPG	40.9	
Feedstock Fuels Emissions in Work-In-Process		40.9
Electricity Emissions Allocated to LPG	14.3	
Electricity Emissions in Work-In-Process		14.3
Feedstock Carbon Content Allocated to LPG	2,122.6	
Feedstock Carbon Content in Work-In-Process		2,122.6
Sum	1,083.7	1,083.7

Phase 4. Transfer emissions from SAF producer's ledger to airline's ledger along with SAF sold

Carbon transferred out from SAF producer to airline (Carbon allocated to SAF sold plus emissions from transporting SAF)

Account	Debit	Credit
Emissions Transferred Out	(11,005.5)	
Direct/Feedstock/Electricity Emissions Allocated to SAF**		(11,005.5)
Transport Emissions Transferred Out	9.6	
Transport Emissions (from SAF producer to Airline)		9.6
Carbon Content Transferred Out	22,366	
Feedstock Carbon Content Allocated to SAF		22,366
Sum	*11,370.1*	*11,370.1*

** Multiple entries are summarized into one for simplicity

No change in naphtha and LPG inventory accounts as they are not sold yet

Airline's ledger

Carbon transferred in from SAF producer

Account	Debit	Credit
Fuels Emissions (SAF)	(10,995.9)	-
Fuels Emissions Transferred In		(10,995.9)
Fuels Carbon Content (SAF)	22,366	-
Fuels Carbon Content Transferred In	-	22,366
Sum	*11,370.1*	*11,370.1*

Carbon transferred in from conventional jet fuel producer

Account	Debit	Credit
Fuels Emissions (Conventional fuel)	3,548	
Fuels Emissions Transferred In		3,548
Fuels Carbon Content (Conventional fuel)	22,366	
Fuels Carbon Content Transferred In	-	22,366
Sum	*25,914*	*25,914*

Note: Each value in this figure represents the total of all carbon forms—CO_2, CH_4, CO, VOCs, and carbon content. The values are aggregated for presentation purposes, while the underlying ledger maintains disaggregated data for each carbon form. The ledger expresses all entries in tons of carbon, serving as a common unit to balance all carbon forms. Source: EFI Foundation and Sesame Sustainability.

Total CO_2 emissions are allocated among the three products based on the energy content. In this example, 85.9% of the combined total CO_2 emissions are allocated to SAF, with 6.0% allocated to naphtha and 8.1% allocated to LPG. The ledger then shows the CO_2 emissions accounting data for SAF product being transferred from the SAF producer's ledger to the customer's (the airline) ledger with the sale of the SAF product. Finally, the transactions for transferred CO_2 emissions and carbon content of SAF are shown along with CO_2 emissions attributed to conventional jet fuel production transferred to the airline's ledger.

Appendix C. Glossary

- **Allocation:** The process of distributing carbon emissions from a single source to multiple products based on causal logic.
- **Attributed CO_2 emissions:** CO_2 emissions from the processing of raw materials and energy inputs upstream of the entity's accounting boundary but transferred to the entity's CO_2 emissions ledger along with the goods and services provided by suppliers at the entry gate.
- **Carbon Border Adjustment Mechanism (CBAM):** A system of fees on imported products, based on the CO_2 emissions associated with their production. The level of the fee could be aligned with a reference price set on CO_2 emissions.
- **Carbon content:** The carbon physically contained within a raw material or product.
- **Carbon mass balance:** A material balance applied specifically to carbon in all chemical forms within a defined system. It ensures that all carbon entering, leaving, and accumulating in the system is quantitatively accounted for, based on the law of conservation of mass.
- **Carbon-differentiated** (product, process, service, market, etc.): A characteristic that is distinguishing based on the amount of CO_2 emissions intensity associated with the production, use, or life cycle, in comparison to similar offerings.
- **CO_2 (or carbon) credit:** The value of CO_2 removal or environmental attribute that is recorded on the ledger.
- **CO_2 emissions abatement:** The capture of CO_2 emissions generated within an entity's operation that would otherwise be released to the atmosphere. The captured CO_2 emissions are subsequently isolated from the environment by storing them for the long term or using them in an inert form in another material.
- **CO_2 emissions intensity:** A ratio of CO_2 emissions to a unit of an activity, such as energy produced (Joules) or a product manufactured (tons), commonly expressed as kilograms of CO_2 ($kgCO_2$) per activity.
- **CO_2 removal:** The process of removing legacy CO_2 emissions from the atmosphere (or CO_2 that has been absorbed into aquatic, marine or terrestrial ecosystems with the potential for re-release to the atmosphere) and isolating it from the environment by storing it for the long term or using it in an inert form in another material.
- **Comprehensive CO_2 emissions accounting:** A definitive set of principles, conventions and rules for quantifying, organizing, and recording transactions affecting CO_2 emissions from all activities contributing to the manufacture of products under the ownership and control of the entity doing the accounting.
- **Direct CO_2 emissions:** CO_2 emissions generated from activities within an entity's accounting boundaries.

- **Double-entry bookkeeping:** An accounting method in which every transaction is recorded twice, once as a debit and once as a credit, in at least two different accounts, ensuring that the accounting equation remains balanced.
- **Emissions Trading System (ETS):** A policy instrument that sets a cap on GHG emissions and allows regulated entities to trade emission allowances. The entities that generate GHG emissions below the level of their allowance can sell excess allowances, and those with GHG emissions exceeding their allowance must buy additional allowances if they cannot otherwise abate the excess emissions.
- **Environmental attributes:** Instruments in the form of contractual terms and conditions or other forms of certificates that represent CO_2 environmental benefits associated with a given activity or commodity. As used in this report, environmental attributes refer to the carbon free emission characteristics of electricity that are separate from the CO_2 emissions attributed to the actual electricity supplied by a 3rd party electricity supplier to the entity's boundary gate.
- **Financial Accounting Standard Board (FASB):** An independent, non-governmental standard-setting body governed by a Board of Directors appointed by the Financial Accounting Foundation. The FASB is responsible for developing Generally Accepted Accounting Principles (GAAP) for U.S. publicly traded companies subject to the U.S. Securities and Exchange Commission. GAAP principles are generally adopted by privately held companies and non-for-profit organizations as well.
- **Gate-to-gate:** A carbon accounting boundary that spans from the point where inputs enter a company's custody and control (entry gate) to the point where the final product is transferred to custody and control of the customer (exit gate).
- **GHG Protocol (GHGP):** An international non-governmental organization founded by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The GHGP develops guidelines for use by the private sector for reporting GHG emissions. The guidelines are voluntary but are typically specified as the method of reporting compliance with various GHG reporting frameworks.
- **International Accounting Standard Board (IASB):** An independent non-governmental organization established and governed by the International Financial Reporting Standards Foundation. The IASB is responsible for development of the International Financial Reporting Standards (IFRS), a set of accounting standards in widespread use outside the U.S.
- **International Organization for Standardization (ISO):** An independent, non-governmental organization currently consisting of representatives from 173 national standards-setting organizations and governed by a rotating board comprised of 20 members. The ISO establishes and oversees technical committees that develop model standards that ca be adopted and implemented by individual countries.

- **Key performance indicators (KPIs):** Measurable values that demonstrate how well an organization or activity is performing against its defined goals or targets.
- **Ledger:** A ledger is collection of accounts for recording accounting transactions. A ledger is typically dual-sided, with transactions entered by date and amount, with each transaction recorded as a debit or credit with a corresponding counter-entry.
- **Life cycle analysis (LCA):** A systematic method for evaluating the environmental impacts associated with all stages of a product's life, from raw material extraction to end-of-life disposal or recycling.
- **Primary data:** Data that is directly measured or derived from other measured data, such as monitored sources of CO_2 emissions or CO_2 emissions calculated based on other physical data such as quantities and carbon content of fuels.
- **Product carbon footprint (PCF):** Total greenhouse gas emissions generated during the entire life cycle of a specific product, commonly expressed as kilograms of CO_2 equivalent ($kgCO_2e$) per product.
- **Product carbon intensity standard (PCIS):** A benchmark that sets CO_2 emissions intensity targets associated with a specific product, commonly expressed as kilograms of CO_2 equivalent ($kgCO_2e$) per unit of product.
- **Product CO_2 emissions intensity:** A ratio of CO_2 emissions to a unit of product, commonly expressed as kilograms of CO_2 equivalent ($kgCO_2e$) per unit of product.
- **Secondary data:** Data derived from various sources external to the entity. Data sources can include industry averages, engineering approximations and data derived from models.

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