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FURTHER CONSIDERATION OF THE DEVELOPMENT OF THE IMO LIFE CYCLE GHG ASSESSMENT (LCA) FRAMEWORK

Study comparing selected existing certification schemes and recommendations for the development of the Sustainable Fuel Certification Schemes (SFCS) framework

Submitted by Pacific Environment

SUMMARY

Executive summary:	This document contains a report by the Maritime Energy and Sustainable Development Centre of Excellence at Nanyang Technological University in Singapore, which studies and compares selected existing certification schemes, including fuel and geographical coverage, GHG emissions quantification, traceability, and other sustainability themes. This work was commissioned by Pacific Environment, and its recommendations provide a reference for further discussion on the development of the Sustainable Fuel Certification Schemes (SFCS) framework.
Strategic direction, if applicable:	3
Output:	3.2
Action to be taken:	Paragraph 6
Related documents:	ISWG-GHG 21/2/5, ISWG-GHG 21/INF.3 and MEPC 85/INF.4

1 Draft guidelines for the recognition of the IMO Sustainable Fuel Certification Schemes (SFCS) are being developed by the Organization. These draft guidelines establish requirements for recognition, procedures for application and assessment, and annual reporting obligations, to ensure that recognized schemes carry out robust certification systems aligned with IMO requirements.

2 A one-day GHG Expert Workshop (GHG-EW 7) was organized by the Secretariat on 15 July 2026 to facilitate understanding of chain of custody (CoC) models allowing for fuel supply chain traceability, to inform the ongoing work on the development of the abovementioned draft guidelines (MEPC 85/INF.4 (Secretariat)).

3 During the workshop, experts examined how CoC models could provide credible traceability of GHG and sustainability attributes through international marine fuel supply chains. Pacific Environment's nominated expert, Dr. Keat Ping Yeoh from the Maritime Energy and Sustainable Development Centre of Excellence at Singapore's Nanyang Technological University, reviewed CoC models including physical segregation, mass balance, and controlled

blending, and highlighted the potential of enhanced traceability measures, including chemical testing or fuel 'fingerprinting' to verify fuel authenticity independently, alongside stronger cross-checks.

4 The analysis was drawn from a study commissioned by Pacific Environment to study and compare selected established certification schemes, including fuel and geographical coverage, GHG emissions quantification, traceability, and other sustainability themes. In addition to recommending enhanced traceability of sustainable fuels through fingerprinting to mitigate the risk of fraud, the study calls for a centralized digital database to log all fuel transactions to prevent suppliers from falsely claiming the same batch of green fuel more than once, and a balanced risk-based approach to cap or phase-out high-risk crop feedstocks to protect ecosystems and food security.

5 The full report is attached in the annex to this document.

Action requested of the Working Group

6 The Working Group is invited to consider the information provided in this document and its annex.

***

ANNEX

THE ROLE OF SUSTAINABLE FUELS CERTIFICATION SCHEMES (SFCS) IN MARITIME DECARBONIZATION



The Role of Sustainable Fuels Certification Schemes in Maritime Decarbonization

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- A representative from a company holding ISCC EU certification in the trader and processing unit scopes
- Jomaine Tang, Certification Manager, Double Helix Tracking Technologies Pte Ltd
- Dr. Gonca Seber, Senior Researcher, International Council on Clean Transportation (ICCT)

We also thank the Maritime and Port Authority of Singapore (MPA) for reviewing the report and providing constructive feedback.

EXECUTIVE SUMMARY

Sustainable Fuels Certification Schemes (SFCS) will be a key part in ensuring compliance in the implementation of the International Maritime Organization's (IMO) Net-Zero Framework. This report contains a review of existing certification schemes applicable to biofuels and e-fuels. The voluntary schemes reviewed include those administered by the International Sustainability & Carbon Certification (ISCC) and Roundtable on Sustainable Biomaterials (RSB). These schemes can be used to demonstrate compliance under the European Union's Renewable Energy Directive (EU RED) and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). National or regional schemes reviewed include Brazil's RenovaBio, the Low Carbon Fuel Standard by the California Air Resources Board (CARB LCFS), and the Renewable Fuel Standard administered by the United States Environmental Protection Agency (US EPA RFS).

From a general survey of the existing sustainability schemes, it was found that ISCC's schemes may dominate the market share, with over 90% of biofuels in the United Kingdom being ISCC-certified, and with over 7,546 ISCC certificates issued in 2024 compared to RSB's 72. This may be due to a larger number of certification bodies recognized to offer ISCC certification. A literature survey on fraud cases was conducted, and the most recent cases of feedstock fraud involved crop-based virgin oil that was misrepresented as waste-based materials, such as used cooking oil (UCO) and palm oil mill effluent (POME) oil. The feedstock fraud was uncovered during the consolidation of certified material volumes for reporting purposes, in which unplausible amounts of UCO and POME feedstocks were declared.

Scheme operators such as ISCC and RSB report to the highest authorities in the governance structure of recognised voluntary schemes, such as the European Commission for the EU RED. In turn, ISCC and RSB oversee Certification Bodies to conduct audits, verification and certification. Under the EU RED and CORSIA, system users along the entire supply chain, from feedstock suppliers to fuel processing units to traders, up to the point of end use, require certification, either individually or as part of a group. National schemes had much simpler governance structures, with verifiers rather than certification bodies, and only fuel suppliers were audited. Audits are the main mechanism behind the sustainability certification to support traceability.

Traceability can be achieved through the forwarding of Proofs of Sustainability (PoS) throughout the supply chain under voluntary schemes. Both on-site and documentary audits are conducted to ensure compliance and the legitimacy of the PoS. Audits are typically conducted annually, however, high-risk supply chains, such as for waste-based materials, may be subject to additional surveillance audits. During audits, plausibility checks are used to determine the legitimacy of the information, such as declared volumes of sustainable material. Chain of custody is the process of how sustainable materials and

the associated information are passed along the supply chain. Physical segregation models are the most stringent, as sustainable materials must be kept separate. Mass balance models allow the mixing of sustainable and non-sustainable materials, while sustainable characteristics are tracked in bookkeeping, and book-and-claim allows complete decoupling between physical sustainable materials and their sustainable characteristics. Physical verification such as using radiocarbon measurement for biogenic content measurement was required under the US EPA RFS for biogas, and such verification may be useful in complementing audits. These traceability measures serve to verify the emissions attributable to the fuel at each step it undergoes.

Quantification of greenhouse gas (GHG) emissions generally covered similar well-to-wake boundaries across the schemes studied, from initial feedstock collection and processing, to fuel production and fuel end-use, i.e. combustion in engines. The largest distinction was in the inclusion of consequential emissions from indirect land-use change (ILUC), which is required in CORSIA schemes and in the two US schemes, but not in schemes under the EU RED.

The rigor of the scope was also studied, covering sustainability aspects beyond GHG emissions. Deforestation was the most important aspect, with strict rules against it. Low-ILUC risk schemes under the ISCC and RSB were also studied. Material certified as low-ILUC risk is exempt from quantitative ILUC emissions and other restrictions placed on crop-based feedstocks. Generally, low-ILUC certification relies on proving that additional yield was achieved on existing crop-land or unused land, and the additional crops would not be financially viable if they were not grown to be processed into biofuels.

The final section contains recommendations for the IMO's SFCS and for Singapore as a global maritime hub. Fingerprinting may be important for both contexts, subject to further methodology development and a cost-benefit analysis. For Singapore, it is also recommended that measures be taken to increase the pool of auditors for sustainability certification schemes.

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LIST OF ACRONYMS

Acronym	Definition
ANP	National Agency of Petroleum, Natural Gas and Biofuels (Brazil)
ARIA	Automated risk assessment
B3	Brasil, Bolsa, Balcão
BDN	Bunker delivery note
CAR	Rural Environmental Registry (Cadastro Ambiental Rural)
CARB	California Air Resources Board
CB	Certification body
CBIO	Decarbonisation credit (Brazil)
CCS	Carbon capture and storage
CCU	Carbon capture and utilization
CI	Carbon intensity
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DCS	Data Collection System
EPA	Environmental Protection Agency (United States)
EU	European Union
EU RED	European Union's Renewable Energy Directive
FPIC	Free, Prior and Informed Consent
GHG	Greenhouse gas
GWP	Global warming potential
HVO	Hydrotreated vegetable oil
ICAO	International Civil Aviation Organization
ILUC	Indirect land-use change
ILO	International Labour Organization
IMO	International Maritime Organization
ISCC	International Sustainability & Carbon Certification
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCFS	Low Carbon Fuel Standard (California)
LCIA	Life cycle impact assessment
LHV	Lower heating value
LNG	Liquefied Natural Gas
LUC	Land-use change
MEPC	Marine Environment Protection Committee
MESD	Maritime Energy and Sustainable Development
MRV	Monitoring, Reporting and Verification
POME	Palm oil mill effluent
PoC	Proof of Compliance
PoS	Proof of sustainability
QAP	Quality Assurance Program
RCF	Recycled carbon fuels
RED	Renewable Energy Directive
RFNBO	Renewable fuels of non-biological origin
RFS	Renewable Fuel Standard (United States)

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RIN	Renewable identification number
RSB	Roundtable on Sustainable Biomaterials
RTFO	Renewable Transport Fuel Obligation (United Kingdom)
SAF	Sustainable aviation fuel
SD	Sustainability declaration
SFCS	Sustainable fuel certification schemes
UCO	Used cooking oil
UDB	Union Database
USDA FAS	United States Department of Agriculture – Foreign Agricultural Service
WtW	Well-to-Wake
WtT	Well-to-Tank
ZNZ	Zero- and near-zero-emission

1 INTRODUCTION AND BACKGROUND

The International Maritime Organization (IMO) has committed its Member States to achieving net-zero greenhouse gas (GHG) emissions from international shipping by or around 2050. Zero- and near-zero-emission fuels (ZNZ fuels), including biofuels and e-fuels produced using renewable electricity, are expected to play a pivotal role in this transition. Sustainability certification will be needed to support the implementation of the IMO's Net Zero Framework. Without robust sustainability certification, there is a risk of non-compliance, greenwashing, or unsustainable production practices that undermine climate goals.

Several established sustainability certification systems are already in operation globally, such as the International Sustainability & Carbon Certification (ISCC) and the Roundtable on Sustainable Biomaterials (RSB). Frameworks and directives such as the EU's Renewable Energy Directive (EU RED) and the International Civil Aviation Organization (ICAO)'s Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) leverage these existing systems, with sustainability certification schemes tailored to their requirements. To ensure credibility and trust, sustainability certification schemes must provide transparent and practical methodologies for emissions accounting, supply chain traceability, and independent verification. The IMO has committed to publishing a list of recognized sustainable fuel certification schemes (SFCS), and a review of existing certification schemes will be useful in guiding the IMO's SFCS. Selected schemes to be reviewed will have a broad certification scope across feedstock and fuel types, as well as chain-of-custody coverage across different categories of certified entities. The review will explore general administration of the schemes, traceability and compliance checking, quantification of GHG fuel intensities and other sustainability criteria. Following the review, recommendations on selected aspects will be provided.

1.1 General Survey of Sustainability Certification Schemes

Sustainability certification schemes can be broadly categorized into recognized voluntary schemes and national schemes.

Recognized voluntary schemes are existing sustainability certification schemes approved under multi-region sustainability directives, such as the EU RED and CORSIA, to verify the compliance of certified sustainable fuels with the relevant sustainability criteria. National schemes are usually region-specific and can also be recognized schemes under multi-region sustainability directives.

Selected sustainability schemes were surveyed regarding market acceptance and utilization rates, scheme coverage across geographical areas and fuel types, and documented non-compliance cases.

1.2 Market Uptake and Reputation

Although many voluntary schemes are approved under the EU RED, market acceptance is best evidenced by observable uptake (the number of certified operators and certificates issued), regulatory recognition (formal eligibility in major compliance regimes), and the extent to which a scheme becomes "default" or "widely accepted" infrastructure for reporting and assurance in a given market. For national schemes, the uptake of renewable fuels may be mandated by law. The figures from these schemes are also reported here.

From the United Kingdom's Renewable Transport Fuel Obligation (UK RTFO) scheme data, voluntary schemes certified 96% of sustainable UK renewable fuel, with ISCC covering 92% in 2023[1]. By 2024, these figures rose to 98% and 94% respectively[2]. Data from the ISCC EU further highlights user preferences: the total number of ISCC EU certificates issued rose from 6,652 in 2023 with system users located in 131 countries[3], to 7,546 in 2024 with system users located in 133 countries[4].

For RSB, the scale is smaller, but its usage is still prevalent in multiple countries. In RSB's 2024 annual EU-directed reporting, the report lists 72 RSB certificates (all scopes), covering 1,112 sites across 29 countries. Although the scheme is recognized within EU frameworks, its market penetration is lower than the ISCC EU scheme. Market participants may favor harmonization around the schemes they already use; for example, if they already hold an ISCC PLUS or ISCC CORSIA certification, obtaining an ISCC EU certification is less resource-intensive. ISCC also offers a larger number of certification bodies (>60)[5], increasing the pool of auditors available for certification, compared to the RSB, which has less than 10 certification bodies[6]. This may explain the overwhelming difference in the number of certifications issued by ISCC and RSB.

[1] Government of UK (2024). Renewable fuel statistics 2023: final report. Available: https://www.gov.uk/government/statistics/renewable-fuel-statistics-2023-final-report/renewable-fuel-statistics-2023-final-report, Accessed: Apr 2026
[2] Government of UK (2025). Renewable fuel statistics 2023: final report. Available: https://www.gov.uk/government/statistics/renewable-transport-fuel-obligation-rtfo-statistics-2024-final-report/renewable-transport-fuel-obligation-rtfo-statistics-2024-final-report, Accessed: Apr 2026
[3] ISCC (2024). Report to the European Commission for the Calendar Year 2023. Available: https://www.iscc-system.org/wp-content/uploads/2024/06/ISCC_Report_To-European_Commission_Calendar-Year_2023.pdf, Accessed: Apr 2026
[4] ISCC (2024). Report to the European Commission for the Calendar Year 2024. Available: https://www.iscc-system.org/wp-content/uploads/2025/05/ISCC_Report_To-European_Commission_Calendar_Year_2024.pdf, Accessed: Apr 2026
[5] ISCC (n.d.) List of cooperating Certification Bodies. Available: https://iscc-system.org/certification/certification-process/certification-bodies/, Accessed: Apr 2026
[6] RSB (n.d.). Certification Bodies. Available: https://rsb.org/certification/certification-bodies/, Accessed: Apr 2026

Under the ICAO CORSIA, ISCC and RSB were approved as voluntary certification schemes by the ICAO Council in June 2023, with a third scheme (ClassNK) added in October 2024[1]. In 2024, ICAO reported 367 CORSIA-certified economic operators, including fuel producers, feedstock/intermediate suppliers, traders and blenders, and 188 kt of CORSIA eligible fuel produced in 2024[2]. Out of these, 25 sustainable aviation fuel (SAF) refineries were certified under CORSIA schemes, representing about 4.4 Mt/year of current CORSIA-certified SAF production capacity and 88% of current SAF production capacity being CORSIA-compliant (25 of 49 operating SAF refineries).

For Brazil's RenovaBio, acceptance is reflected in (i) statutory embedding and (ii) the scale of regulated entities and certified production plants. RenovaBio is established in Brazilian law as part of national energy policy and explicitly linked to life-cycle assessment mechanisms and climate objectives, primarily to reduce greenhouse gas emissions[3][4]. In operational terms, the United States Department of Agriculture – Foreign Agricultural Service (USDA FAS) reports that as of 2 August 2024, Brazil's fuels regulator, the National Agency of Petroleum, Natural Gas and Biofuels (ANP) had licensed 422 biofuel plants for operation, of which 333 were licensed under RenovaBio (291 ethanol plants, 38 biodiesel plants, and 4 biomethane plants) and authorized to issue decarbonization credits (CBIOs)[5]. It also reports cumulative issuance of 105 million CBIOs from 2019 to December 2023, and that 12 million CBIOs had been issued since January 2024 as of mid-July 2024. Since CBIOs are traded on Brazil's exchange B3 (Brasil, Bolsa, Balcão) and are defined as a unit equivalent to one ton of CO_2 avoided, the programme's market acceptance is structurally tied to a functioning credit market and recurring annual distributor obligations[6].

For the California Low Carbon Fuel Standard (LCFS), acceptance can be proxied by the number of reporting entities and the volume of credit/deficit activity. In official compliance

[1] ICAO (2024). CORSIA Approved Sustainability Certification Schemes. Available: https://www.icao.int/sites/default/files/environmental-protection/CORSIA/Documents/CORSIA%20Eligible%20Fuels/ICAO-document-04-Approved-SCSs-October-2024.pdf, Accessed: Apr 2026

[2] ICAO (2025). Aviation and Cleaner Energy. Available: https://www.icao.int/sites/default/files/EURNAT/Documents/EUR%20and%20Nat%20Docs/Environment/2025%20Regional%20Seminar%20on%20Environment/Presentations/07.1-ICAO-SAF-Update-2025-Baku.pdf, Accessed: Apr 2026

[3] Government of Brazil (2017). Law No. 13,576 – Chapter I – Brazilian Biofuel Policy. Available: https://www.gov.br/anp/pt-br/assuntos/renovabio/arq/law-13576-2017.pdf, Accessed: Apr 2026

[4] Tiburcio, R. S., de Macêdo, T. R., & Neto, A. M. P. (2023). Brazilian Biofuels Policy (RenovaBio): Overview and generation of decarbonization credits by biodiesel production facilities. Energy for Sustainable Development, 77, 101334.

[5] USDA & GAIN (2024). Biofuels Annual. Available: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels+Annual_Brasilia_Brazil_BR2024-0022.pdf, Accessed: Apr 2026

[6] B3 (n.d.). ESG Products and Services - Decarbonization credit (CBIO). Available: https://www.b3.com.br/en_us/b3/sustainability/esg-products-and-services/decarbonization-credit-cbio/, Accessed: Apr 2026

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reporting for the 2024 data year, the California Air Resources Board (CARB) reported that 570 entities actively reported activity under the LCFS program during 2024, that the program achieved 100% compliance, and that 37,385,770 credits and 23,481,028 deficits were generated in the 2024 data year[1]. This suggests relatively significant participant coverage across the California transportation fuels system.

In addition, for the United States Environmental Protection Agency's Renewable Fuel Standard (US EPA RFS), market acceptance is driven by federal blending obligations and the scale of mandated volume targets. The targets are quantified in renewable identification numbers (RINs), where one RIN represents one ethanol-equivalent gallon of renewable fuel[2]. The EPA's volume target for 2025 is 34.39 billion RINs, with specific targets for cellulosic biofuels, biomass-based diesel, advanced biofuels, and renewable fuels[3]. This indicates a very large compliance-driven renewable fuels market; however, because RFS is primarily an energy/volume and GHG-threshold mechanism rather than a sustainability/land-criteria certification regime, acceptance under RFS does not necessarily translate into acceptance for sustainability claims in other markets unless additional sustainability certification layers are applied.

1.3 Coverage in geographical areas

The geographic coverage differs for voluntary certification systems (e.g. ISCC EU, ISCC CORSIA, RSB) and geographically bounded regulatory programmes (RenovaBio, LCFS, and the RFS). The European Commission describes both ISCC EU and RSB as having global geographic coverage within the scope of EU-recognised voluntary schemes[4]. The 2024 report also characterises the geographic concentration of newly issued certificates: Europe remained the most relevant area with 3,997 certificates in 2024, versus 3,750 in 2023, followed by South and East Asia and Latin America[5]. This also implies that "EU-anchored" sustainability certification has, in practice, become a global supply-chain system rather than a regional compliance scheme.

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[1] CARB (2024). 2024 LCFS Compliance and Credit Clearance Market Information. Available: https://ww2.arb.ca.gov/sites/default/files/2025-05/2024%20LCFS%20Credit%20Clearance%20Market%20Notice%20and%20Compliance%20Information.pdf, Accessed: Apr 2026

[2] US EPA (n.d.). Overview of the Renewable Fuel Standard Program. Available: https://www.epa.gov/renewable-fuel-standard/overview-renewable-fuel-standard-program, Accessed Apr 2026

[3] US EPA (n.d.). Final Renewable Fuels Standards Rule for 2023, 2024, and 2025. Available: https://www.epa.gov/renewable-fuel-standard/final-renewable-fuels-standards-rule-2023-2024-and-2025, Accessed: Apr 2026

[4] European Commission (n.d.). Voluntary Schemes. Available: https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/voluntary-schemes_en, Accessed: Apr 2026

[5] ISCC (2025). Report to the European Commission for the Calendar Year 2025. Available: https://iscc-system.org/wp-content/uploads/2026/05/ISCC_Report_To European_Commission_Calendar_Year_2025_website.pdf, Accessed: Jun 2026

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RenovaBio's reach is primarily domestic for Brazilian transport fuels, but its certification architecture explicitly includes both producers and importers of biofuels in the issuance chain for CBIOs[1], which indicates a legal pathway to incorporate cross-border biofuel flows, even if the dominant coverage remains tied to Brazilian production plants and Brazilian distributor obligations. Currently, the Brazil-recognised decarbonisation credential does not automatically function as a portable sustainability certificate in other markets unless SFCS recognises equivalence, sets conversion/bridging rules, or requires dual certification for exported volumes[1].

For California's LCFS and the US EPA RFS, geographic scope is determined by jurisdictional demand with potentially global supply chains. The regulations apply to transportation fuels sold, supplied, or offered for sale in designated US regions and assigns reporting responsibility to entities such as producers or importers of fuels[2]. The programs include mechanisms for participation by foreign renewable fuel producers in certain circumstances and by importers, making geographic coverage broader than US production even if the compliance obligation is within the US[3]. This creates a structurally open perimeter: the policy is geographically bounded in where fuels are consumed, but not necessarily in where the fuels or feedstocks are produced.

1.4 Coverage in fuel types

Fuel-type breadth determines (i) what parts of the energy transition the system can credibly cover today (e.g., conventional biofuels, biomethane, e-fuels), and (ii) how resilient the system is to technology and policy evolution (e.g., a shift from crop biofuels towards wastes/residues, e-fuels, hydrogen derivatives, or co-processing). The EU voluntary scheme framework explicitly spans biofuels/bioliquids/biomass fuels and extends to renewable fuels of non-biological origin (RFNBOs), and recycled carbon fuels (RCF), with schemes expected to verify GHG savings and traceability of sustainability characteristics. Within that framework, the Commission states that ISCC EU covers agricultural biomass, forest biomass, wastes and residues, and covers "all" fuel types, including RFNBOs and RCFs, with full chain of custody provisions (including biomethane beyond production)[4]. RSB's coverage is the

[1] Government of Brazil (2017). Law No. 13,576 – Brazilian Biofuel Policy. Available: https://www.gov.br/anp/pt-br/assuntos/renovabio/arq/law-13576-2017.pdf, Accessed: Apr 2026
[2] CARB (2025). Attachment A-1 Available: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2024/lcfs2024/atta1.pdf, Accessed: Apr 2026
[3] US EPA (n.d.) RINs Generated Transactions. Available: https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rins-generated-transactions, Accessed: Apr 2026
[4] European Commission (n.d.). Voluntary Schemes. Available: https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/voluntary-schemes_en, Accessed: Apr 2026

same as ISCC EU, except that it excludes forestry biomass[1] [2]. Some recognized voluntary schemes have limited feedstock and chain of custody coverage. For example, the Red Tractor scheme only provides certification for agricultural biomass from farms to the first intake point.

CORSIA's fuel scope covers a range of defined CORSIA-eligible fuels, which can be broadly categorised into biofuels and e-fuels depending on the production process and major feedstock.

RenovaBio's operational fuel scope is anchored in Brazil's deployed biofuel mix and currently manifests at scale in ethanol, biodiesel, and biomethane certification. This shows coverage across liquid and gaseous biofuels but with a focus on bio-ethanol[3].

California's LCFS is among the broadest in fuel coverage for a demand-side decarbonisation programme. CARB's regulatory text lists transportation fuels covered by the LCFS that include fossil fuels and low-carbon substitutes across liquids, gases, and electricity: examples include bio-CNG/bio-LNG, electricity, compressed/liquefied hydrogen, denatured fuel ethanol (E100), neat biomass-based diesel (B100/R100), and "alternative jet fuel", alongside other liquid and non-liquid fuels[4]. It also illustrates the program relies on pathway carbon-intensity accounting and crediting rules.

The US RFS fuel-category is broad, covering nested categories of cellulosic biofuel, biomass-based diesel, advanced biofuel, and conventional renewable fuel. EPA describes the programme via D-codes assigned to the aforementioned categories. The codes are used to structure compliance and crediting, and sets volumetric targets across those categories[5].

1.5 Documented cases of fraud

Existing sustainable fuel certification and crediting systems have experienced multiple forms of fraud and misreporting, particularly in systems linked to tradable credits and waste-based feedstocks. Fraud types include feedstock fraud, double claiming, false sustainability claims and credit fraud.

[1] RSB (n.d.). A guide to the RSB standard. Available: https://rsb.org/wp-content/uploads/2020/07/RSB-Guide-to-the-RSB-Standard-1.pdf, Accessed: Apr 2026
[2] RSB (2025). RSB Standard for EU Market Access. Available: https://rsb.org/wp-content/uploads/2025/01/rsb-std-11-001-v.5.2-standard-for-eu-market-access.pdf, Accessed: Apr 2026
[3] USDA & GAIN (2024). Biofuels Annual. Available: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels+Annual_Brasilia_Brazil_BR2024-0022.pdf, Accessed: Apr 2026
[4] CARB (2025). Attachment A-1 Available: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2024/lcfs2024/atta1.pdf, Accessed: Apr 2026
[5] US EPA (n.d.) Overview of the Renewable Fuel Standard Program. Available: https://www.epa.gov/renewable-fuel-standard/overview-renewable-fuel-standard-program, Accessed: Apr 2026

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Feedstock fraud typically involves misrepresenting the origin or classification of feedstocks, such as falsely declaring virgin oils as waste-based materials including used cooking oil (UCO). Double claiming occurs when the same fuel batch, sustainability attribute, or emissions reduction is claimed multiple times across different transactions or regulatory systems. False sustainability claims involve the use of invalid or fraudulent certificates to market fuels as compliant with sustainability requirements. Credit fraud refers to the creation or trading of credits linked to non-existent or improperly verified fuel production.

These risks are particularly significant for waste-based fuels, including UCO, tallow, and other residues, where physical traceability is inherently difficult and supply chains are often international and fragmented. Several major fraud cases have been documented across existing systems.

1.5.1 US Renewable Fuel Standard (RFS) – RIN credit fraud

One of the most significant documented fraud cases occurred under the US Renewable Fuel Standard (RFS) between 2011 and 2013[1]. Under the RFS, renewable fuel producers generate Renewable Identification Numbers (RINs), which are tradable compliance credits linked to biofuel production volumes.

EPA investigations found that several companies generated fraudulent RINs without producing the corresponding biofuel. These companies falsified production records and sold invalid credits into the market. EPA enforcement actions estimated that more than 140 million fraudulent RINs were generated, involving hundreds of millions of dollars in market transactions. In response, EPA introduced the Quality Assurance Program (QAP), which added independent third-party verification requirements for RIN generation and validation.

This case demonstrated that credit-based compliance systems are highly vulnerable when verification systems rely excessively on self-reported production data without sufficient independent oversight.

1.5.2 European UCO fraud cases under ISCC EU and related systems

Multiple investigations and industry reports have raised concerns regarding fraud risks associated with waste-oil supply chains in Europe. These waste-based oil feedstocks include used cooking oil (UCO) and oil recovered from palm oil mill effluent (POME). In several reported cases, virgin palm oil or other vegetable oils were allegedly misclassified

[1] Yacobucci, B.D. (2014). Analysis of Renewable Identification Numbers (RINs) in the Renewable Fuel Standard (RFS). Available: https://www.congress.gov/crs-product/R42824, Accessed: Jun 2026

as UCO or POME-oil. This may be due to favorable policy treatment of waste-based fuels, which can be double-counted in renewable energy targets[1].

A 2024 report by Transport & Environment highlighted abnormal growth in reported UCO imports into the European Union, particularly from China and Southeast Asia, with import volumes exceeding plausible collection potential in some regions[2]. A similar trend was observed for POME-oil, where it was estimated that the amount of POME-oil consumed is double that of its global collection potential.[3] These reports identified significant risks of falsified collection records and feedstock misclassification within waste-oil supply chains.

These cases highlighted structural vulnerabilities in waste-based fuel certification systems, particularly where certification relies heavily on documentary evidence and where physical verification of feedstock origin is difficult.

[1] T&E (2024). How sustainable are advanced and waste biofuels? Available: https://www.transportenvironment.org/articles/how-sustainable-are-advanced-and-waste-biofuels, Accessed: Apr 2026
[2] T&E (2024). UCO (Unknown Cooking Oil): High hopes on limited and suspicious materials. Available: https://www.transportenvironment.org/articles/uco-unknown-cooking-oil-high-hopes-on-limited-and-suspicious-materials Accessed: Apr 2024
[3] T&E (2025). Palm oil in disguise? Available: https://www.transportenvironment.org/articles/palm-oil-in-disguise Accessed: Apr 2026

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2 TRACEABILITY – GOVERNANCE AND CHAIN OF CUSTODY

To verify compliance and to discourage fraudulent practices as described above, traceability covers areas such as governance of the certification schemes, audit requirements, chains of custody, documentary proofs of sustainability and central databases.

2.1 Governance Structures & Requirements for Certification Bodies

This section covers the administration structure of sustainability certification schemes. Voluntary schemes and national schemes are administered differently.

2.1.1 Recognised Voluntary Schemes

The highest authorities in the governance structure of the EU RED[1] and CORSIA[2] are the European Commission and the ICAO Council respectively. These authorities, in turn, approve voluntary schemes to ensure that sustainable fuels are produced in compliance with the relevant criteria.

The voluntary schemes are administered by multi-stakeholder organizations, such as the ISCC and RSB. Typically, the organization is governed by a general assembly with a multi-stakeholder board. The number of stakeholder groups on the board differs between schemes, e.g. ISCC has three[3], while RSB has five[4]. Stakeholders may be comprised of feedstock producers, processors, traders, research institutes, non-governmental organizations, and public sectors. Stakeholder committees are also established under continuous improvement initiatives to address specific concerns, such as chemical analysis of feedstocks to enhance the integrity of certified supply chains[5].

The certification schemes are managed by an operational arm overseen by the governing board[6]. Its responsibilities include authorizing, monitoring, and cooperating with certification bodies. Annual reports are submitted to the highest governing authorities and typically cover certification statistics, governance updates, and the outcomes of integrity monitoring activities. Integrity audits may be conducted on certification bodies and system users.

[1 3 6] ISCC (2025). ISCC EU 102 Governance V4.2. Available: https://iscc-system.org/certification/iscc-documents/, Accessed: Apr 2026
[2] ISCC (2023). ISCC CORSIA 102 Governance V2.0. Available: https://iscc-system.org/certification/iscc-documents/, Accessed: Apr 2026
[4] RSB (n.d.). Meet our members. Available: https://rsb.org/membership/meet-our-members/, Accessed: Apr 2026
[5] ISCC (2025). New ISCC working group: Chemical analytics of feedstocks. Available: https://iscc-system.org/new-iscc-working-group-chemical-analytics-of-feedstocks/, Accessed: Apr 2026

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Certification bodies audit and certify sustainability system users after verifying their compliance with the relevant requirements[1] [2]. They must either be formally recognized by a competent national authority or hold accreditation in accordance with ISO/IEC 17065[3] or ISO/IEC 17021[4]. In addition, certification bodies conducting audits of actual GHG values are required to hold ISO 14065 accreditation[5]. Equivalent standards and accreditations are also acceptable, provided they are properly justified. The relationships among the parties in the governance structure are illustrated in Figure 2-1.

The certification bodies must ensure that their auditors are qualified for their duties. Auditors must undergo and pass mandatory training modules before they can conduct audits. Certain audit types require auditors to pass specific training modules, such as GHG modules for actual GHG values and waste and residues modules for elements in a waste and residue supply chain. Auditors cannot consecutively audit the same system user for more than three years.

System users maintain an internal management system specifying procedures for compliance with the sustainability scheme requirements[6]. Good practices for sustainability, GHG emissions accounting and traceability should be specified and applied. Employee roles in relation to the handling of sustainable materials should also be specified. The management system also includes a reporting system to ensure that key records are kept and organized, including weighbridge tickets and bill of ladings for sustainable materials received and dispatched, the related purchase and sales contracts and records of internal audits and applicable corrective actions.

[1] ISCC (2025). ISCC EU 103 Requirements for Certification Bodies and Auditors. Available: https://iscc-system.org/certification/iscc-documents/, Accessed: Apr 2026
[2] RSB (2025). RSB Procedure for Certification Bodies and Auditors. Available: https://rsb.org/wp-content/uploads/2025/05/rsb-pro-70-001_procedure-cbs-and-auditors_v-5.0.pdf, Accessed: Jul 2026
[3] ISO/IEC 17065 (2012). Conformity assessment — Requirements for bodies certifying products, processes and services. Available: https://www.iso.org/standard/46568.html, Accessed: Apr 2026
[4] ISO/IEC 17021(2015). Conformity assessment — Requirements for bodies providing audit and certification of management systems Part 1: Requirements. Available: https://www.iso.org/standard/61651.html, Accessed: Apr 2026
[5] ISO/IEC 14065 (2020). General principles and requirements for bodies validating and verifying environmental information. Available: https://www.iso.org/standard/74257.html, Accessed: Apr 2026
[6] ISCC (2025). ISCC EU 203 Traceability and Chain of Custody V4.2. ISCC EU 203. Available: https://www.iscc-system.org/wp-content/uploads/2025/04/ISCC_EU_203_Traceability_and_Chain-of-Custody_4.2.pdf, Accessed: Apr 2026

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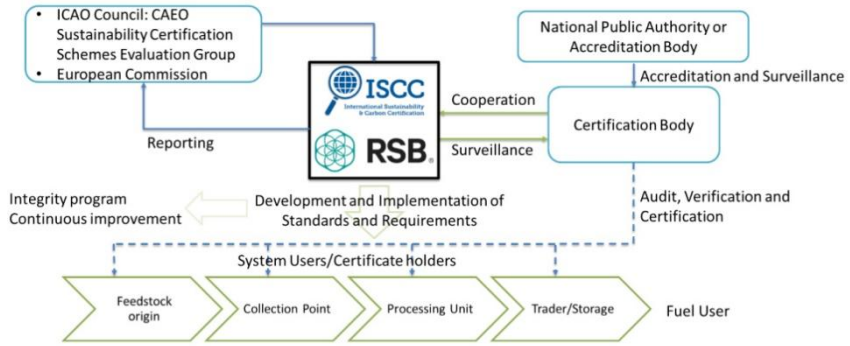


Figure 2-1: Illustration of a typical governance structure of recognized voluntary schemes

2.1.2 National Schemes

National or state sustainability schemes generally have more centralized governance structures compared to recognized voluntary schemes. Audits on fuel reporting entities (typically fuel suppliers such as producers and importers) are typically conducted by inspection firms or verifiers, akin to certification bodies under voluntary schemes. However, these verifiers are directly authorized and overseen by the government agency responsible for administering the scheme. In such systems, system users commonly report directly to the government authority rather than to the verifiers themselves. Unlike voluntary schemes, there is usually no separate independent organization responsible for operating or governing the certification system. This difference in governance structure is potentially due to the smaller number of system users, since national schemes are region-specific. Figure 2-2 illustrates the typical governance structure of national schemes, with RenovaBio[1] and the CARB LCFS[2] as examples.

[1] Government of Brazil (2026). RenovaBio. Available: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/renovabio-1/renovabio-ingles, Accessed: Apr 2026

[2] California Air Resources Board (2025). Overview of the Low Carbon Standard. Available: https://ww2.arb.ca.gov/sites/default/files/2025-11/LCFS%20Basics_post11-20-25_final.pdf, Accessed: Apr 2026

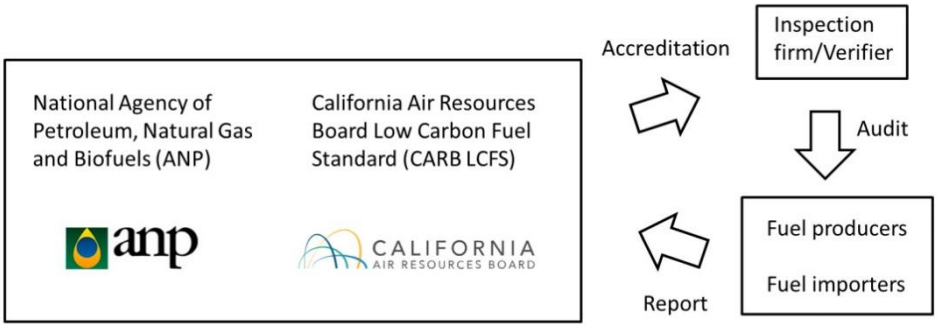


Figure 2-2 Typical governance structure of national schemes

2.2 Certification and Transaction Requirements along the Supply Chain

Under the sustainability schemes associated with EU RED and CORSIA, all elements of the sustainable fuel supply chain must be individually certified, except for feedstock origins[1 2 3]. Sustainable materials sold by certified entities must be accompanied by a transaction proof, also known as a sustainability declaration (SD) or proof of sustainability (PoS). SDs contain a unique number, supplier and recipient details, relevant purchase contract numbers, product and raw material types, amount of sustainable material supplied, chain-of-custody model applied and a sustainability statement, among others. Each SD must correspond to the dispatch of an equivalent amount of sustainable material. SDs will be surrendered to the relevant authorities as evidence that a fuel batch is EU RED compliant, and double issuance is prohibited. When documentary proof is legitimately required for compliance with a different sustainability directive, a Proof of Compliance (PoC) can be issued for a certified fuel batch if the original SD has been surrendered[4].

When they are not certified, feedstock origins or points of origin may be managed by a certified central office. They may also provide sustainable materials to certified collection points and traders. These individual points of origin are eligible for certification although it is not mandatory. In the absence of certification, these points of origin are subject to

[1] ISCC (2025). ISCC EU 203 Traceability and Chain of Custody V4.2. ISCC EU 203. Available: https://www.iscc-system.org/wp-content/uploads/2025/04/ISCC_EU_203_Traceability_and_Chain-of-Custody_4.2.pdf, Accessed: Apr 2026
[2] RSB (2025). RSB EU RED Procedure for Traceability V4.0 [RSB-PRO-11-001-20-001]. Available: https://rsb.org/wp-content/uploads/2025/05/rsb-pro-11-001-20-001_rsb-eu-red-traceability_v.4.0.pdf, Accessed: Apr 2026
[3] ISCC (2026). ISCC CORSIA 203 Traceability and Chain of Custody Version 2.1. Available: https://iscc-system.org/wp-content/uploads/2026/07/ISCC_CORSIA_203_Traceability_and_Chain-of-Custody_2.1.pdf, Accessed: July 2026
[4] ISCC (2024). ISCC Proof of Compliance Guidance Document. Available: https://www.iscc-system.org/wp-content/uploads/2024/12/ISCC-Guidance-Document-Proof-of-Compliance-V1.0.pdf, Accessed: Jun 2026

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monitoring by the central office, collection points and traders, and they may be audited as part of the certification of the monitoring entity. Points of origins issue self-declarations to the central offices and first collection points when they are not eligible to issue sustainability declarations.

Under the EU RED, transactions involving liquid biofuels sold into the European market must be recorded in the Union Database (UDB) once it is fully implemented. System users, including first collection points, fuel and feedstock traders, and processing units, are subject to the database requirements[1]. Use of the UDB enhances traceability and reduces the risk of double claiming under the EU RED.

Under the national and regional schemes, typically only the fuel supplier is monitored, although the LCFS will require third-party certification and chain of custody documentation for biomass beginning in 2028[2]. Transactions are verified yearly. Credits are generated in fixed amounts (e.g. per ton of CO_2 reduced), while the number of credits is variable. Credits are also logged and retired into a central system.

2.3 Audit requirements and risk-based audits

On-site and documentary audits are typically conducted annually. System users must provide a list of records documenting the inflow and outflow of sustainable materials, including sustainability declarations as well as supply and sales contracts.

Sustainability schemes provide risk assessment direction to guide the scope of the audits[3] [4]. Complete document checks are required in the high-risk category, while random sampling may be sufficient for lower-risk categories. Risk is assessed and categorized based on factors such as the completeness and accessibility of sustainability system documents, quantity of waste material generated and pending legal action related to sustainability themes. The risk level is sometimes explicitly stated, e.g. a high-risk level is assigned to points of origin handling palm oil mill effluent (POME), an amendment made considering the mis-declaration of feedstock mentioned in 1.5. Automated risk assessment (ARIA) platforms are also mandatory for specific locations such as palm plantations in Malaysia and Indonesia

[1] RSB (n.d.). Union Database for Biofuels (UDB). Available: https://rsb.org/certification/udb-union-database-for-biofuels/, Accessed: Jun 2026
[2] CARB (2025). Updates to the Low Carbon Fuel Standard and the Role of Certification. Available: https://iscc-system.org/wp-content/uploads/add-from-server-reloaded/Update-on-the-Low-Carbon-Fuel-Standard-LCFS-and-the-Role-of-Certification-%E2%80%93-Carmen-Meialua-Air-Pollution-Specialist-California-Air-Resources-Board-CARB-US.pdf, Accessed Jun 2026
[3] ISCC (2025). ISCC-EU-204 Risk management. Available: https://www.iscc-system.org/wp-content/uploads/2025/04/ISCC_EU_204_Risk_Management_v4.2.pdf, Accessed Jun 2026
[4] RSB (2021). Procedure for Risk Management. Available: https://rsb.org/wp-content/uploads/2024/06/RSB-PRO-60-001-vers-3.3_Procedure-for-Risk-Management.pdf, Accessed Jun 2026

under ISCC EU[1]. The platform-generated report includes an initial evaluation of the protection level of biodiverse and carbon-rich land.

Aside from the certification audit, surveillance audits after an initial certification audit are mandatory for system users in a high-risk supply chain handling both virgin and waste-based materials[2]. Any system user handling sustainable materials (e.g. waste, residues) eligible for incentives, such as double-counting of the energy content of advanced biofuels, is deemed to have a high risk. For example, collection points handling POME oil, or traders dealing with both used cooking oil and virgin palm oil would be deemed high-risk.

If a system user is certified under multiple sustainability schemes, documents submitted to these schemes must be made available for auditing. This serves as a measure to uncover and discourage double claiming or repeated usage of a sustainable fuel batch to meet regulatory requirements under different directives.

2.4 Plausibility checks

To ensure compliance, auditors need to exercise their judgment in determining the legitimacy of documents and whether declared amounts are reasonable. This is the essence of a plausibility check.

One example of a plausibility check is determining whether the declared amount of POME oil from a particular oil palm processing plant is reasonable. Information such as the actual amount of palm oil produced and the typical quantity of POME oil generated per ton of palm oil is required for the plausibility check. Plausibility checks are a tool to detect and deter misdeclarations of waste amounts and intentional waste production.

Plausibility checks are also applied in verifying actual GHG emissions. The calculated actual GHG emissions of a fuel may be compared against typical and default values, which are official GHG intensity values provided by the authorities for selected pathways. Under the ISCC EU scheme, justification is required when the actual value deviates by >10% from a typical value or by > 30% from a default value[3]. Thus, a reliable database of typical and default values is important in guiding the plausibility checks.

2.5 Chain of custody models

Under sustainable fuel certification schemes, a chain of custody would be the process whereby sustainable inputs and outputs, as well as the associated information, are

[1] [2] ISCC (2025). ISCC EU 203 Traceability and Chain of Custody V4.2. ISCC EU 203. Available: https://www.iscc-system.org/wp-content/uploads/2025/04/ISCC_EU_203_Traceability_and_Chain-of-Custody_4.2.pdf, Accessed: Apr 2026

[3] ISCC (2025). ISCC EU 205 V4.2: Greenhouse Gas Emissions. Available: https://www.iscc-system.org/wp-content/uploads/2024/01/ISCC_EU_205_Greenhouse-Gas-Emissions_v4.1_January2024.pdf, Accessed: Apr 2026

transferred, monitored and controlled as the sustainable material progresses through each entity along the supply chain[1]. The sustainable material undergoes physical transfers and transformations throughout the supply chain, from the initial feedstock to conversion into fuel to the final point before fuel usage, i.e., bunkering for marine fuels.

A chain of custody model is the specific implementation approach used to control the traceability of sustainable materials as they move through the supply chain. The sustainable output cannot exceed the sustainable input in all chain of custody models. Four chain of custody models are discussed here, with varying degrees of linkage between the physical transfer of sustainability characteristics across the supply chain. The physical segregation and mass balance chains of custody are accepted under the EU RED and CORSIA.

2.5.1 Physical segregation

Under the physical segregation or identity preservation chain of custody, certified sustainable materials must remain separated from non-certified materials throughout the supply chain[2]. This is illustrated in Figure 2-3. In addition, the physical segregation chain-of-custody model cannot be applied if mass balance was used as the tracking model at an upstream unit in the supply chain.

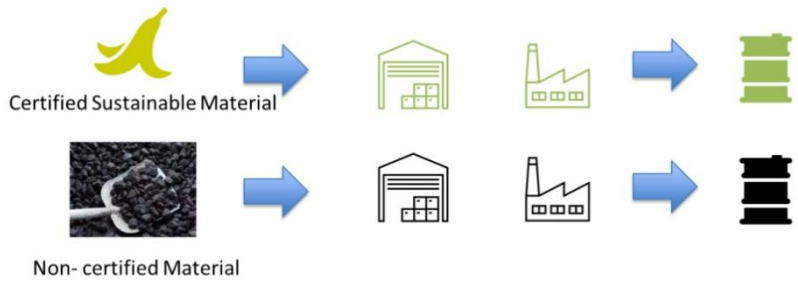


Figure 2-3 Illustration of the physical segregation chain of custody

Physical segregation is further classified into hard and soft identity preservation. When hard identity preservation is applied, feedstocks of different sustainability characteristics, such as material type and country of origin, must be physically separated throughout the supply chain. The physical amount and type of sustainable material are the same as recorded in the quantity bookkeeping.

In soft identity preservation, certified sustainable feedstocks of similar sustainability characteristics may be stored and processed together, but they must be separated in

[1] ISO 22095 (2020). Chain of custody — General terminology and models. Available: https://www.iso.org/standard/72532.html, Accessed: Apr 2026
[2] RSB (2025). RSB EU RED Procedure for Traceability. Available: https://rsb.org/wp-content/uploads/2025/05/rsb-pro-11-001-20-001_rsb-eu-red-traceability_v.4.0.pdf, Accessed: Jun 2026

quantity bookkeeping. Raw materials of the same type but from different countries may be physically mixed.

2.5.2 Mass balance

When the mass balance chain of custody is applied, certified sustainable materials and non-certified materials can be physically mixed throughout the supply chain[1], as shown in Figure 2-4. Unlike in physical segregation, since the materials are mixed, individual properties are lost, and it is difficult to physically identify the sustainable materials, especially after processing. Sustainability characteristics are assigned to materials and tracked via quantity bookkeeping records. Mass balances under the EU RED and CORSIA schemes are site-, scheme- and material-specific, and a physical link where the sustainable material is received at the specified site is required[2] [3]. Mass balance bookkeeping records are audited by the certification bodies.



Figure 2-4 Illustration of the mass balance chain of custody

A specific period (typically not exceeding 3 months for most operators and not exceeding 12 months for farms and plantations) must be set, over which the total amount of sustainable input matches the sustainable output. Figure 2-5 illustrates the flow of sustainable and non-sustainable materials over a 3-month period, assuming a conversion factor of 1. A deficit occurs in the 1st Month, where the sustainable output exceeds the sustainable input. Deficits are possible during a mass balance period, but they must be rectified by the end[4]. The overall balance shows that the sustainable input equals the output over the bookkeeping period.

[1] [4] ISCC (2025). ISCC EU 203 Traceability and Chain of Custody V 4.2. Available: https://iscc-system.org/certification/iscc-documents/, Accessed: Jun 2026
[2] ISCC (2026). ISCC CORSIA 203 Traceability and Chain of Custody Version 2.1. Available: https://iscc-system.org/wp-content/uploads/2026/07/ISCC_CORSIA_203_Traceability_and_Chain-of-Custody_2.1.pdf, Accessed: July 2026
[3] RSB (2020). RSB Procedure for Traceability of RSB Certified Material [RSB-PRO-20-001 (Version 3.2)]. Available: https://rsb.org/wp-content/uploads/2024/06/RSB-PRO-20-001_RSB-Procedure-for-Traceability_v3.2.pdf, Accessed: July 2026

Positive balances of sustainable material can be carried forward to the next mass balancing period, provided that the corresponding amount of sustainable material is in stock.

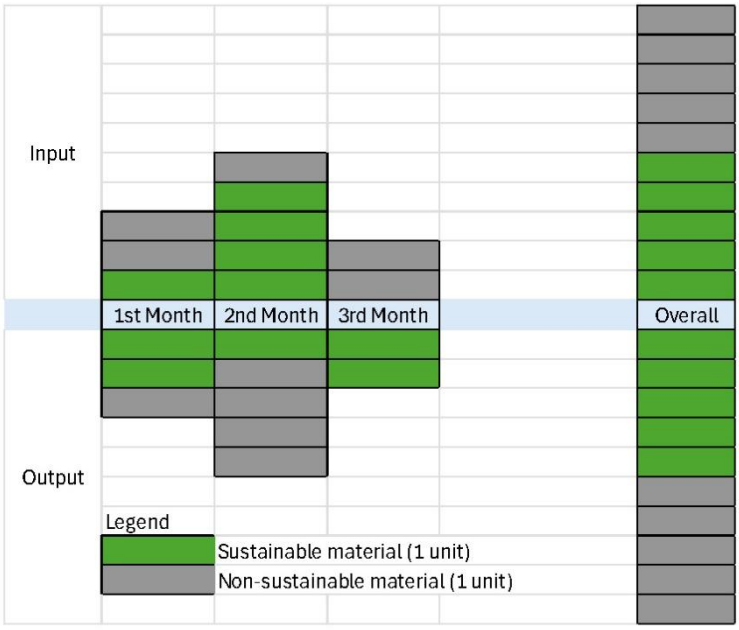


Figure 2-5 Illustration of the flow of sustainable and non-sustainable materials

When sustainable bio-based and non-sustainable fossil materials are co-processed under the EU RED to produce physically and chemically identical fuels, a conversion factor needs to be defined to appropriately assign the amount of sustainable output under the mass balance chain of custody[1]. The conversion factor is a dimensionless term and it can be calculated using four methods: material determination (by mass), energetic determination (by lower heating value (LHV)), yield method (proportional increase in product output due to the addition of a known amount of sustainable material) and radiocarbon measurement. When any of the former three methods are used to determine the conversion, radiocarbon measurements shall be used to quantify the biogenic carbon content for verification. As an example, the conversion factor is calculated using the energetic determination method in Figure 2-6.

In the example, sustainable hydrotreated vegetable oil (HVO) is co-processed in an oil refinery unit with non-sustainable naphtha, a fossil fuel. Several products are obtained after the co-processing, and all LHVs, as well as the mass of each input and output material, are known. The total energy input is 44900 MJ and the total energy output is 42350 MJ. Out of

[1] RSB (2025). RSB EU RED Procedure for Traceability. Available: https://rsb.org/wp-content/uploads/2025/05/rsb-pro-11-001-20-001_rsb-eu-red-traceability_v.4.0.pdf, Accessed: Jun 2026

the energy input, 4400/44900 or 9.8% stems from the sustainable material. Therefore, 9.8% of the energy output can be sold as sustainable products. The sustainable output is 4150 MJ.

Feedstock	LHV (MJ/kg)	Mass (kg)
HVO	44	100
Naphtha	45	900

Product	LHV (MJ/kg)	Mass (kg)	Energy (MJ)
Fuel Gas	47	150	7050
Butane	45	100	4500
Pygas	47	200	9400
Ethane	48	350	16800
Propane	46	100	4600
		Total	42350

	Input (MJ)	Output (MJ)
Sustainable	44 MJ/kg x 100 kg = 4400	4400/44900 x 42350 = 4150
Non-sustainable	45 MJ/kg x 900 kg = 40500	40500/44900 x 42350 = 38200
Total	44900	42350

Figure 2-6 Sample calculation of the conversion factor (adapted from ISCC[1])

Mass balance is sometimes applied for production where sustainable materials are only recorded in quantity bookkeeping. One example is when the sustainable input is renewable natural gas from a natural gas network containing primarily fossil-based natural gas. In this case, no physical sustainable material is received, and the co-processing rules do not apply. Documentary proofs, such as purchasing contracts, are required under these circumstances.

2.5.2.1 Illustration of sustainability characteristic assignment using GHG values

Physical Sustainable Input		
	GHG value	
Batch 1	300	kgCOe/t
Batch 2	400	kgCOe/t
Batch 3	500	kgCOe/t

Mixing (Conversion Factor = 1)

Batch 4

Physical Sustainable Output
Batch 5
Batch 6
Batch 7
Batch 8
Batch 9

Bookkeeping

Input			
Batch	Type	GHG value (kgCO2e/t)	Amount (t)
1	Sustainable	300	1000
2	Sustainable	400	600
3	Sustainable	500	400
Total			2000

Company Internal Process (mixing)			
Batch	Type	GHG value (kgCO2e/t)	Amount (t)
4	Sustainable	300	1000
		400	600
		500	400
Total			2000

Output			
Batch	Type	GHG value (kgCO2e/t)	Amount (t)
5	Sustainable	300	500
6	Sustainable	300	500
7	Sustainable	400	300
8	Sustainable	400	300
9	Sustainable	500	400
Total			2000

Figure 2-7 Example of bookkeeping for batches of sustainable material with different GHG values[2]

[1] ISCC (2025). ISCC EU 203-02 Mass Balance Guidance, Version 1.4. Available: https://www.iscc-system.org/wp-content/uploads/2025/12/ISCC-EU-Mass-Balance-Guidance-Document_Version-1.2_Final_22122025.pdf, Accessed: Aug 2026

[2] ISCC (2025). ISCC EU 203 Traceability and Chain of Custody V 4.2. Available: https://iscc-system.org/certification/iscc-documents/, Accessed: Jun 2026

Figure 2-7 shows an example of how GHG values can be attributed between sustainable inputs and outputs. Since there is a total of 1000 t of sustainable feed with a GHG value of 300 $kgCO_2e/t$, a total of 1000 t or 2 x 500 t batches of sustainable product can be certified since the conversion factor is 1. In ISCC EU[1]/CORSIA[2] and RSB EU RED[3], batches with different GHG values have to be separated in bookkeeping, as aggregation of batches of different GHG values into batches with averaged GHG values is not allowed, e.g., in Figure 2-7, a single output batch of 2000 t with an average GHG value of 370 kg CO_2e/t cannot be claimed. Aggregation is only allowed if the highest GHG value is applied, e.g., a 2000 t batch with a GHG value of 500 $kgCO_2e/t$ can be claimed. In contrast, aggregation of the GHG values with assignment of an average GHG value is allowed under RSB ICAO CORSIA[4], e.g. a single output batch of 2000 t with an average GHG value of 370 kg CO_2e/t can be claimed.

2.5.2.2 Illustrative cases of mass balance

The mass balance chain of custody can be implemented with varying levels of rigor, although this distinction is not usually made in the recognized voluntary schemes. The rolling average percentage method in ISCC PLUS is one way of implementing the mass balance chain of custody[5]. In this method, the ratio of sustainable input material fluctuates within a defined averaging period, and an average percentage claim of the output can be certified as sustainable. Sustainability characteristics cannot be attributed to output outside of the averaging period. The attributed output can only be kept in the bookkeeping if the physical output from the corresponding averaging period is still in inventory. In addition, sustainable output can only be claimed after the sustainable input has been processed; receiving or storing the sustainable material prior to using it as input is not sufficient for the claim.

The credit method is a less strict approach to mass balance than the rolling average percentage method. In the credit method under ISCC PLUS[6], the quantified, attributable credit represents sustainability characteristics derived from sustainable input material. The credits from certified sustainable inputs can be assigned to the sustainable output, subject to proper conversion factors. Unlike the rolling average percentage method, these

[1] ISCC (2025). ISCC EU 203 Traceability and Chain of Custody V 4.2. Available: https://iscc-system.org/certification/iscc-documents/, Accessed: Jun 2026
[2] ISCC (2026). ISCC CORSIA 203 Traceability and Chain of Custody Version 2.1. Available: https://iscc-system.org/wp-content/uploads/2026/07/ISCC_CORSIA_203_Traceability_and_Chain-of-Custody_2.1.pdf, Accessed: July 2026
[3] RSB (2025). RSB EU RED Procedure for Traceability. Available: https://rsb.org/wp-content/uploads/2025/05/rsb-pro-11-001-20-001_rsb-eu-red-traceability_v.4.0.pdf, Accessed: Jun 2026
[4] RSB (2020). RSB Procedure for Traceability of RSB Certified Material [RSB-PRO-20-001 (Version 3.2)]. Available: https://rsb.org/wp-content/uploads/2024/06/RSB-PRO-20-001_RSB-Procedure-for-Traceability_v3.2.pdf, Accessed: July 2026
[5 6] ISCC (2025). ISCC PLUS 203 – 2 CHAIN OF CUSTODY V 1.1. Available: https://iscc-system.org/wp-content/uploads/2025/11/ISCC_PLUS_203-2_Chain-of-Custody_v1.1.pdf, Accessed: Aug 2026

credits can be forwarded between mass balance periods without any restrictions on the physical availability or usage of the sustainable material.

2.5.3 Controlled Blending/Content Ratio Accounting

This chain of custody is not applicable under the EU RED or CORSIA[1], but it is offered by the ISCC PLUS[2] and RSB Global schemes. Under this chain of custody, sustainable and non-sustainable inputs are co-processed in a known and fixed ratio. Unlike the mass balance chain of custody, the output must contain a constant, verifiable amount of sustainable material.

2.5.4 Book and claim

Book & Claim is a chain of custody model that allows the physical sustainable product to be completely decoupled from its specific sustainability characteristics[3]. The characteristics are transferred as credits through a dedicated registry. It is similar to mass balance as the amount of sustainable output cannot exceed the input. However, unlike mass balance, the bookkeeping is not site-specific, leading to difficulties in compliance verification.

2.6 Traceability requirements for e-fuels and recycled carbon fuels

Renewable electricity is used to produce renewable fuels of non-biological origin (RFNBO), generally known as e-fuels. Renewable electricity and recycled carbon used to produce e-fuels must meet specific requirements in schemes under the EU RED.

2.6.1 Requirements for Renewable Electricity Sources

In ISCC EU, renewable electricity used in the production of e-fuels must originate from non-biogenic sources such as solar, wind, hydropower and geothermal[4].

For renewable electricity sources directly connected to the e-fuel production site, electricity generation must have begun operation not earlier than 3 years before the e-fuel production unit. The renewable electricity source should not be connected to the national grid. If it is connected, a smart meter can be used to measure electricity flow to prove that grid

[1] RSB (2020). RSB Procedure for Traceability of RSB Certified Material [RSB-PRO-20-001 (Version 3.2)]. Available: https://rsb.org/wp-content/uploads/2024/06/RSB-PRO-20-001_RSB-Procedure-for-Traceability_v3.2.pdf, Accessed: July 2026
[2] ISCC (2025). ISCC PLUS 203 – 2 CHAIN OF CUSTODY V 1.1. Available: https://iscc-system.org/wp-content/uploads/2025/11/ISCC_PLUS_203-2_Chain-of-Custody_v1.1.pdf, Accessed: Aug 2026
[3] RSB (2021). Global Stakeholders Invited to Participate in a Consultation on the RSB Book & Claim Manual. Available: https://rsb.org/2021/12/02/global-stakeholders-invited-to-participate-in-a-consultation-on-the-rsb-book-claim-manual/, Accessed: Aug 2026
[4] ISCC (2024). ISCC EU 202-6 Renewable Fuels of Non-Biological Origin (RFNBOs) and Recycled Carbon Fuels (RCFs), Version 1.4. Available: https://www.iscc-system.org/wp-content/uploads/2025/10/ISCC_EU-205-1_RFNBOs_RCF_GHG-Emissions_v1.4.pdf, Accessed: Aug 2025

electricity is not used in e-fuel production. Power purchase agreements or guarantees of origin may be supplied as documentary proof during audits.

Grid electricity qualifies as a renewable energy source when the renewable energy share of the power mix exceeds 90% or when the grid mix's emission intensity is below 18 gCO_2e/MJ in the bidding zone where the RFNBO production occurs. A bidding zone is defined as "the largest geographical area within which market participants are able to exchange energy without capacity allocation". The concept of a bidding zone is defined in the EU context, but it may not be present in other countries. Equivalent concepts are acceptable in other countries, with guidance on the determination of equivalence provided to auditors.

RFNBOs can also be produced from grid electricity when it can be proven that the electricity used for the production reduced the need for downward redispatching of renewable electricity. Downward redispatching occurs when a power generating installation is instructed to reduce its electricity generation to prevent grid overload. Renewable electricity capacity can be better utilized when it is used to produce RFNBOs, instead of being redispatched downward.

When the aforementioned requirements for renewable electricity from the grid are not met, grid electricity for RFNBO production may be considered fully renewable when additionality, geographical correlation and temporal correlation can be proven. Additionality refers to an increase in renewable capacity (e.g. in the RFNBO production site) or the purchase of renewable energy by the RFNBO producer. To meet the geographical correlation criteria when purchasing renewable energy, the supply contract should be with a renewable power generation installation located within the same bidding zone or interconnected bidding zone as the RFNBO production facility. Temporal correlation requires proof that the purchased renewable electricity and RFNBO were produced in the same calendar month (before 1 Jan 2030), or during the same one-hour period (1 Jan 2030 onward).

2.6.2 Requirements for Carbon Sources to Produce RCFs

RCFs must be produced using carbon from non-renewable waste or industrial byproducts[1]. Proof that these waste or byproduct streams are not generated intentionally for RCF production is required. Liquid and solid waste streams should be deemed unfit for recovery, while non-renewable gases should be unavoidable emissions or incidental byproducts from industrial activities. Carbon emissions can only be considered avoided when they have been accounted for upstream through an effective carbon pricing system.

[1] RSB (2025). RSB EU Standard for Renewable Fuels of Non-Biological Origin (RFNBOs) and Recycled Carbon Fuels (RCFs). Available: https://rsb.org/wp-content/uploads/2025/11/rsb-std-11-103-v.1.0-eu-standard-for-rfnbos-and-rcfs.pdf, Accessed: Jun 2026

2.7 Enhanced traceability measures

In addition to documentary evidence and audits, physical measurements have been used for compliance verification. In the US EPA RFS, radiocarbon measurements must be conducted to determine the renewable fraction of natural gas produced from a mix of renewable and non-renewable feedstocks[1]. Furthermore, the US EPA RFS is concluding provisions to limit biogas producers to supplying biogas for a single use, e.g. they can only supply it as renewable natural gas in a pipeline or renewable liquefied natural gas, but not both. The provision is intended to prevent the double claiming of credits generated from biogas.

Currently, traceability aided by physical measurements is usually limited to radiocarbon testing to determine biogenic carbon content. This method can be used on all biofuels, and sustainable fuels produced from biogenic carbon dioxide and carbon dioxide from direct air capture. However, e-fuels require different measurements.

Singapore has developed a fingerprinting methodology with methanol as a case study, where laboratory tests performed on the fuel can be used to identify specific sustainability characteristics[2], such as biogas or e-hydrogen used for fuel production. Fingerprinting of the fuel would not be applicable in certain scenarios under the mass balance chain of custody, such as when renewable natural gas is injected into a gas grid and withdrawn as fuel or feedstock. In these cases, fingerprinting would have to be performed earlier in the supply chain, e.g. before the RNG is injected into the grid. The fingerprinting framework is a potential alternative to additional surveillance audits for ensuring the integrity of sustainable fuels in future high-risk supply chains.

[1] Federal Register (2023). Renewable Fuel Standard (RFS) Program: Standards for 2023-2025 and Other Changes. Available: https://www.federalregister.gov/documents/2023/07/12/2023-13462/renewable-fuel-standard-rfs-program-standards-for-2023-2025-and-other-changes, Accessed: Jun 2026

[2] MESD (2024). Methanol Fuel Assurance and Fingerprinting. Available: https://www.maritimeinstitute.sg/wp-content/uploads/2024/09/MESD_Methanol-Fingerprinting.pdf, Accessed: Jun 2026

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3 QUANTIFICATION OF GREENHOUSE GAS EMISSIONS

Lifecycle GHG accounting and chain-of-custody systems are closely interconnected components of sustainability fuel certification systems. While GHG accounting quantifies the environmental performance of a fuel pathway, chain-of-custody mechanisms provide the traceability framework necessary to ensure that the sustainability attributes and emission reductions associated with a specific fuel are consistently transferred and verified throughout the supply chain. Without robust traceability and verification procedures, lifecycle emission values may become disconnected from the physical fuel flows or environmental attributes they are intended to represent, creating risks of double-counting, double-claiming, or misallocation of emission reductions. Consequently, most SFCSs integrate GHG accounting requirements with traceability and mass-balance or book-and-claim systems to maintain the credibility and integrity of sustainability claims across complex fuel supply chains.

Building upon this traceability foundation, lifecycle GHG accounting provides the quantitative basis for evaluating the environmental performance of certified fuel pathways. Unlike conventional fuel standards that primarily focus on fuel quality and technical specifications, SFCSs require systematic quantification of emissions across the entire fuel lifecycle, including feedstock production, processing, transport, conversion, distribution, and final fuel use. The calculated lifecycle emission intensity is typically expressed in gCO_2e/MJ and compared against a fossil-fuel comparator or regulatory benchmark.

GHG quantification serves several functions across existing systems. First, it determines eligibility under sustainability regulations such as the EU RED and CORSIA. Second, it directly affects credit generation under systems such as LCFS, RenovaBio, and RFS, where lower-carbon fuels receive greater economic value. Third, it supports comparability across different fuel pathways, enabling regulators and market participants to assess relative environmental performance.

For maritime applications, lifecycle GHG accounting presents additional complexities compared with land-based fuel systems. Marine fuels are often produced in one region, bunkered in another, and consumed globally across multiple jurisdictions, creating challenges for verifying the chain of custody and ensuring consistency in sustainability claims. In addition, marine fuel pathways increasingly involve electricity-intensive e-fuels, biofuels and gaseous fuels transported under cryogenic conditions, where upstream emissions, methane leakage, renewable electricity sourcing, and transport emissions may dominate total lifecycle performance. Operational factors specific to shipping, including vessel type, engine technology, voyage profile, bunkering location, and methane slip from dual-fuel engines, may further affect well-to-wake (WtW) emissions outcomes. As a result, relatively small methodological differences in lifecycle accounting can lead to substantial

differences in certified carbon intensity values, compliance costs, and fuel competitiveness in maritime applications.

In this section, GHG accounting rules and methodologies extracted from different schemes are explored[1] [2] [3] [4] [5] [6] [7].

3.1 System boundaries and emissions scope

Lifecycle system boundaries and emissions scope may vary across existing schemes. These choices affect calculated carbon intensity values and the comparability of certified fuels. Most existing systems apply lifecycle-based approaches, but the treatment of upstream, operational, and downstream emissions differs across schemes. For example, emissions from fuel combustion, carbon capture and permanence, and end-use allocation methods are handled differently across schemes, leading to variations in reported lifecycle carbon intensity values.

Under the ISCC EU tailored for the EU RED, lifecycle accounting generally follows a WtW approach, covering emissions from feedstock cultivation or collection through fuel combustion. The methodology includes emissions from cultivation, land-use change, processing, transport, distribution, and combustion, while also allowing certain emission reductions and credits under specified conditions.

ISCC CORSIA and RSB CORSIA similarly apply lifecycle-based accounting frameworks, although the methodologies are adapted for aviation fuel pathways and ICAO requirements. In contrast, the broader RSB Global sustainability framework adopts a more comprehensive sustainability-oriented accounting approach, with more explicit consideration of co-products, land-use effects, and wider system-level impacts beyond purely regulatory GHG compliance.

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[1] ISCC (2025). ISCC EU 205 V4.2: Greenhouse Gas Emissions. Available: https://www.iscc-system.org/wp-content/uploads/2024/01/ISCC_EU_205_Greenhouse-Gas-Emissions_v4.1_January2024.pdf, Accessed: Apr 2026

[2] ISCC (2023). ISCC CORSIA 205 Life Cycle Emissions V4.2. https://www.iscc-system.org/wp-content/uploads/2023/12/ISCC_CORSIA_205_Life_Cycle_Emissions_2.0.pdf, Accessed: Apr 2026

[3] RSB (2025). RSB Greenhouse Gas Calculation Methodology RSB-STD-03-001 V3.2. Available: https://rsb.org/wp-content/uploads/2025/07/rsb-std-01-003-01-v3.2.pdf, Accessed: Apr 2026

[4] CARB (n.d.). LCFS Pathway Certified Carbon Intensities. Available: https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities, Accessed: Apr 2026

[5] ANP & GNB (2025). RenovaBio program regulations and lifecycle assessment methodology. Available: https://www.gov.br/anp, Accessed: Apr 2026

[6] US EPA (2024). Renewable Fuel Standard program. Available: https://www.epa.gov/renewable-fuel-standard-program, Accessed: Apr 2026

[7] IMO (2024). 2024 Guidelines on life cycle GHG intensity of marine fuels (MEPC.391(81)). Available: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.391(81).pdf, Accessed: Apr 2026

The California LCFS applies one of the most comprehensive carbon-intensity accounting frameworks among existing systems. The LCFS methodology evaluates emissions across the full fuel lifecycle and relies heavily on pathway-specific modelling, transport assumptions, electricity carbon intensity, and fuel-distribution pathways. RenovaBio and EPA RFS also use lifecycle approaches, but primarily to determine regulatory eligibility and credit-generation thresholds rather than for direct fuel certification alone.

For maritime applications, the IMO Net-Zero Framework and the LCA Guidelines were adopted under MEPC.391(81) to establish a dedicated Well-to-Wake accounting framework for marine fuels. The methodology defines WtT emissions to include feedstock extraction or cultivation, land-use change, fuel production and conversion, transport, storage, distribution, and bunkering emissions, while also allowing accounting adjustments for soil carbon accumulation and carbon capture and storage (CCS) under specified conditions. In addition, Tank-to-Wake emissions are separately addressed to account for onboard fuel combustion and methane slip where applicable.

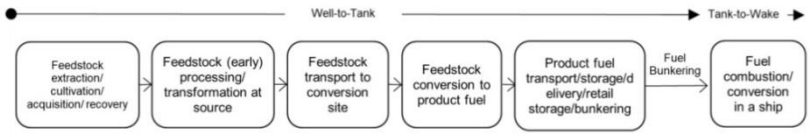


Figure 3-1 Generic well-to-wake supply chain from IMO MEPC.391(81)

Based on this lifecycle structure, the IMO methodology defines WtT emissions GHG_{WtT} as follows:

$$GHG_{WtT} = e_{fecu} + e_l + e_p + e_{td} - e_{sca} - e_{ccs}$$

CCS-related adjustment item e_{ccs} is further defined as:

$$e_{ccs} = C_{SC} - e_{CC} - e_t - e_{st} - e_x$$

Compared with other existing schemes, the IMO framework places stronger emphasis on harmonized global fuel comparability across maritime fuel pathways, while maintaining compatibility with several existing lifecycle accounting principles derived from EU RED and aviation-related sustainability methodologies. Table 3-1 summarizes the differences in lifecycle system boundaries and emission accounting scopes across major certification schemes, with particular attention to the treatment of CCS-related emissions and accounting adjustments. Unlike other schemes, the US EPA RFS evaluates lifecycle GHG emissions on a pathway-specific basis and does not establish separate accounting terms for CO_2 capture, transport, or geological storage.

Table 3-1 Comparison of lifecycle emission accounting boundaries (with those of the IMO LCA guidelines) across major certification schemes

Term	Explanation	ISCC EU and RSB EU RED	ISCC CORSIA and RSB CORSIA	California LCFS	RenovaBio	USA EPA RFS
e_{fecu}	Feedstock extraction / cultivation / acquisition / recovery	✓	✓	✓	✓	✓
e_l	Direct land-use change (dLUC) emissions	✓	✓	✓	✓	✓
e_p	Feedstock processing and fuel conversion emissions	✓	✓	✓	✓	✓
e_{td}	Transport, distribution, storage, delivery, bunkering	✓	✓	✓	✓	✓
e_{sca}	Soil carbon accumulation credits	✓	✓	△	△	△
e_{ccs}	Carbon capture and storage credits	✓	✓	✓	△	△
C_{sc}	Net CO_2 captured and permanently stored	△	△	✓	△	✗
e_{cc}	Emissions from CO_2 capture/compression	△	△	✓	△	△
e_t	Emissions from CO_2 transport to storage site	△	△	✓	✗	✗
e_{st}	Emissions from long-term CO_2 storage	△	△	✓	✗	✗
e_x	Additional CCS-related emissions	△	△	✓	✗	✗

Note:

- ✓ = explicitly considered or incorporated in methodology
- △ = partially considered, indirectly addressed, or only applicable for certain pathways/projects
- ✗ = generally not explicitly included

A major implication is that identical fuels may receive different certified carbon intensity values under different schemes due to variations in system boundaries, upstream assumptions, electricity-carbon-intensity treatment, methane accounting, and co-product methodologies. This creates interoperability challenges for internationally traded fuels. For maritime SFCS, boundary definition will be particularly important for e-fuels, LNG-based fuels, biofuels, and waste-derived fuels, where upstream electricity sourcing, methane leakage, transport distance, and feedstock assumptions can dominate total lifecycle emissions. Harmonisation of WtW boundaries and emissions scope will therefore be critical to ensure comparability across marine fuel pathways and regulatory systems.

3.2 Actual and default values in GHG accounting methodology

Existing schemes, including ISCC EU, ISCC CORSIA, RSB, California LCFS, RenovaBio, and EPA RFS, apply a combination of default values and actual values in lifecycle GHG accounting.

- Default Values: Pre-determined conservative values provided by regulators. These are intended for operators who cannot provide primary data. While they simplify compliance, they often include a "conservative premium," resulting in a higher (less

favorable) carbon intensity score. Default values in the EU RED are derived from the typical values and a pre-determined factor to account for variations in parameters across technologies, regions and markets[1]. Under CORSIA, GHG emissions for each pathway were calculated by a designated institution and independently verified[2]. In addition, a midpoint-value definition was employed to determine the pathway-specific default values, as results varied due to differing parametric assumptions, process inputs, and other factors. When two analyses exhibited a difference lower than 10% of the jet fuel baseline, the default value is taken from the average of the results. For differences beyond the 10% threshold, the pathway was either re-defined into two separate pathways or harmonization of the parametric assumptions was carried out.

- Typical Values: Representative estimates of the greenhouse gas emissions for fuel production pathways or specified stages of the pathways. In the EU RED, typical values are representative of the EU's consumption[3]. The Joint Research Center of the European Commission (JRC) defines the input values for the typical GHG emissions of biofuels with data derived from reports and databases of emission inventories published by international organizations (e.g., IPCC), peer-reviewed journal publications, and primary data provided by stakeholders and industrial associations[4]. The JRC's input data review process included expert and stakeholder workshops, where comments were compiled and considered in finalizing the computations.
- Actual Values: GHG emissions calculated based on primary data collected directly from the supply chain (e.g., utility bills, meter readings). Utilizing actual values is the primary mechanism for producers to demonstrate efficiency and secure a competitive advantage in the market.

Most systems therefore operate under a hybrid approach, where the use of actual or default values depends on the lifecycle stage, fuel pathway, and data availability. Under ISCC EU and the EU RED in general, economic operators may use total default values for the entire

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[1] HURTIG, O., BOUTER, A., BESSEAU, R., BUFFI, M. and SCARLAT, N. (2026). Updating GHG emission values of biofuels and biomass fuels in Annex V & VI of Directive (EU) 2018/2001, Publications Office of the European Union, Luxembourg. Available: https://data.europa.eu/doi/10.2760/1027379, JRC142012.

[2] ICAO. (2020). CORSIA supporting document: CORSIA Eligible Fuels – Life Cycle Assessment Methodology Version 2. Available: https://www.icao.int/sites/default/files/sp-files/environmental-protection/CORSIA/Documents/CORSIA_Supporting_Document_CORSIA%20Eligible%20Fuels_LCA_Methodology_V2.pdf, Accessed: July 2026

[3] European Commission (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018L2001, Accessed: July 2026

[4] Edwards, R., Padella, M., Giuntoli, J., Koeble, R., O` Connell, A., Bulgheroni, C. and Marelli, L. (2017). Definition of input data to assess GHG default emissions from biofuels in EU legislation: Version 1c - July 2017, EUR 28349 EN, Publications Office of the European Union, Luxembourg. Available: https://publications.jrc.ec.europa.eu/repository/handle/JRC104483

fuel lifecycle, actual values calculated for specific pathways, or a combination of disaggregated default values and actual values for different lifecycle stages. For example, default values may be applied to cultivation or transport stages, while actual operational data are used for processing or electricity consumption. This structure provides flexibility while maintaining comparability across standard biofuel pathways. However, total default values are available only for a limited number of fuel pathways and feedstock combinations, meaning that many operators rely on combinations of disaggregated default values and actual values for lifecycle emission calculations.

Across schemes, the determination of these default values relies on core methodological principles: the conservative principle (safety margin), standardized boundary conditions, and representative pathway modeling. Default values are intentionally calibrated to represent upper-tier industry emissions (e.g., a 40% markup from the typical value in EU RED processing defaults for liquid biofuels[1,2]) to prevent underestimating carbon intensity and incentivize primary data collection. Technical variables, such as LHV energy allocation rules and background inventory databases, are hardcoded into default models like BioGrace[3] and RenovaCalc[4] to ensure comparability.

Consequently, frameworks differ in how heavily they incorporate these defaults based on their underlying regulatory mechanics. California LCFS and RenovaBio rely more heavily on actual operational data because lifecycle emissions directly determine credit generation and economic value. Similarly, ISCC CORSIA and RSB apply more pathway-specific accounting approaches due to the variability of SAF supply chains and renewable electricity inputs. The use of actual and default values also differs across lifecycle stages. Table 3-2 defines where and how different values are applied across the lifecycle.

Table 3-2 Requirements on actual and default values on lifecycle stages

Stage	Data Type Preference	Key Parameters	Data Source & Compliance
Feedstock Production	Actual / Default	Fertilizer use Agricultural inputs Collection records	Defaults: Regional averages. Actuals: Farm-level input logs; requires 12 months of continuous data for audit.

[1] European Commission (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018L2001, Accessed: July 2026

[2] HURTIG, O., BOUTER, A., BESSEAU, R., BUFFI, M. and SCARLAT, N. (2026). Updating GHG emission values of biofuels and biomass fuels in Annex V & VI of Directive (EU) 2018/2001, Publications Office of the European Union, Luxembourg. Available: https://data.europa.eu/doi/10.2760/1027379, JRC142012.

[3] BioGrace Project (2015). Harmonisation of GHG Calculations for biofuels. Available: https://old.etipbioenergy.eu/other-resources/biograce-harmonisation-of-ghg-calulcations-for-biofuels, Accessed: July 2026

[4] ANP (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis) (2020). RenovaBio Methodology & RenovaCalc GHG Calculation Tool Documentation. Resolution No. 758/2018 / Official Tool. Available: https://www.gov.br/anp/pt-br/assuntos/renovabio/renovacalc, Accessed: July 2026

Land Use Change	Actual (Mandatory)	Satellite data Land-use records	Derived from satellite imagery or land use records. Defaults are rarely applicable for direct land conversion.
Transport & Distribution	Actual / Default	Transport distance Transport mode Fuel use	Defaults: Based on standard shipping routes. Actuals: Bill of Lading (B/L) records and actual fuel consumption per ton-km.
Processing / Refining	Primarily Actual	Electricity Fuel consumption Process efficiency	Most schemes (EU RED, LCFS) discourage generic defaults for processing. Inputs from site-specific utility bills and production data.
Waste & Residues	Default and actual	Default upstream assumption Actual downstream data	Typically considered "zero emissions" at the point of collection; Default upstream assumption Actual downstream data: processing and transport are accounted for.

Across most schemes, processing stages increasingly rely on actual operational data because energy consumption, electricity carbon intensity, and conversion efficiency strongly affect lifecycle emissions. In contrast, upstream agricultural stages more commonly use default or regional-average values where direct monitoring is difficult.

A common trend across existing systems is the gradual transition from default-value approaches toward greater reliance on verified actual data, particularly for e-fuels, RFNBOs, SAF, and other electricity-intensive pathways. While default values simplify compliance and improve standardization, actual values provide greater differentiation between pathways and are increasingly necessary for accurate carbon-intensity accounting and credit generation. As regulatory frameworks rely more on primary operational data, robust supply-chain traceability and rigorous third-party verification become critical to ensuring data integrity, preventing double counting, and validating chain-of-custody compliance across complex supply chains. This shift necessitates advanced tracking mechanisms, such as standardized Mass Balance or Book and Claim registries, alongside digital chain-of-custody platforms to audit site-specific energy inputs and feedstock origins transparently.

3.3 Lifecycle GHG calculation methodologies and equations

Existing sustainable fuel certification systems broadly apply lifecycle-based GHG accounting methodologies, with accounting boundaries as described in 3.1. However, slight differences may exist in calculation structure, emissions treatment, pathway specificity, and regulatory objectives. Most schemes quantify lifecycle emissions on an energy-normalized basis, typically expressed in gCO_2e/MJ fuel, but the level of methodological detail varies depending on whether the system is designed primarily for sustainability certification, regulatory compliance, or carbon-credit generation.

Table 3-3 Lifecycle stages included in major GHG accounting frameworks

Lifecycle stage	ISCC EU / ISCC CORSIA	RSB Global	California LCFS	RenovaBio	EPA RFS	IMO MEPC.391(81)
ILUC accounting	X ✓	△	✓	△	✓	X
Feedstock transport	✓	✓	✓	✓	✓	✓
Fuel processing / conversion	✓	✓	✓	✓	✓	✓
Electricity consumption	✓	✓	✓	✓	✓	✓
Chemical and auxiliary inputs	✓	✓	✓	✓	△	✓
Fuel distribution and storage	✓	✓	✓	✓	✓	✓
Methane slip	△	✓	✓	△	✓	✓
Emission avoidance credits	△	✓	✓	△	△	△
Co-product allocation	✓	✓	✓	✓	✓	✓
Infrastructure lifecycle emissions	X	✓	△	△	X	X

Note:

- ✓ = explicitly considered or incorporated in methodology
- △ = partially considered, indirectly addressed, or only applicable for certain pathways/projects
- X = generally not explicitly included

As shown in Table 3-3, the core lifecycle structure is broadly consistent across schemes. All systems include emissions associated with feedstock production, transport, fuel conversion, distribution, and fuel use. However, differences emerge in the treatment of ILUC, methane slip, emission avoidance credits, excess renewable electricity credits, and infrastructure lifecycle emissions, while co-product allocation is consistently addressed across all frameworks.

ISCC EU and ISCC CORSIA share a largely similar lifecycle accounting framework. Both explicitly incorporate co-product allocation and account for excess renewable electricity under specific fuel pathways, such as RFNBOs, while methane slip, emission avoidance credits, and infrastructure lifecycle emissions are only partially addressed through pathway-dependent provisions. In contrast, RSB adopts a more comprehensive lifecycle accounting methodology, explicitly incorporating methane slip, emission avoidance credits, excess renewable electricity, infrastructure lifecycle emissions, and co-product allocation,

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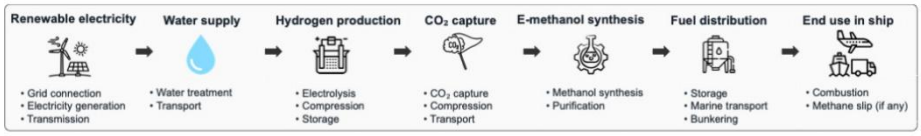
while also providing broader consideration of sustainability-related issues, including ILUC. CORSIA applies a quantified ILUC default value to crop-based fuels (unless certified as Low ILUC-risk), whereas ISCC EU manages ILUC risks through feedstock caps and phase-out policies rather than adding an emission value.

California LCFS applies one of the most detailed CI-based methodologies among existing systems. Lifecycle emissions are calculated using pathway-specific carbon intensity models that explicitly account for methane slip, indirect land-use change, excess renewable electricity, and emission avoidance credits, thereby supporting continuous pathway verification. Because lifecycle performance directly determines credit generation, LCFS places strong emphasis on operational data and continuous pathway verification.

RenovaBio similarly links lifecycle emissions directly to CBIO generation through Energy-Environmental Efficiency Scores. EPA RFS differs from LCFS and RenovaBio in that it primarily applies lifecycle threshold assessment rather than continuous carbon-intensity calculation. The system evaluates whether fuel pathways satisfy predefined GHG-reduction thresholds relative to fossil-fuel baselines. Consequently, EPA RFS places relatively less emphasis on explicit accounting of infrastructure lifecycle emissions and excess renewable electricity credits than LCFS, while maintaining explicit consideration of methane slip and indirect land-use change through pathway-specific assessment.

Compared with existing certification schemes, the IMO framework places stronger emphasis on harmonized WtW accounting for maritime fuels, particularly regarding methane slip, RFNBO electricity accounting, while excluding infrastructure lifecycle emissions and explicit ILUC accounting.

To illustrate why these methodological differences matter in practice, Figure 3-2 presents a comparative accounting example based on a representative renewable methanol pathway. The example follows the complete fuel lifecycle, including renewable electricity generation, hydrogen production through electrolysis, CO_2 capture and processing, methanol synthesis, fuel distribution, bunkering, and final fuel use. By mapping the system boundaries and emission sources considered under different certification frameworks, the comparison demonstrates how the same physical fuel pathway may be assigned different lifecycle carbon intensity values depending on the treatment of process-based emissions. This example highlights that differences in accounting boundaries and methodological assumptions can lead to substantially different certified GHG intensities, with direct implications for regulatory compliance, sustainability claims, credit generation, and the economic competitiveness of maritime fuels.



Certification Framework	Infrastructure	Electricity Generation & Transmission	Water Supply	Hydrogen Production	CO_2 as feedstock for fuel synthesis	CO_2 Transport	E-Methanol Synthesis & Purification	Fuel Distribution & Storage (incl. bunkering)	End Use (Combustion)
IMO GHG Fuel Standard (Draft)	Not required	✓ Required (well-to-gate electricity)	Optional	✓ Required	✓ Required (if included in pathway)	✓ Required	✓ Required	✓ Required (up to ship)	✓ Required (WTT) ✓ Combustion (Tank-to-Wake)
ISCC EU (RED III)	Optional	✓ Required (with emission factors)	✓ Required	✓ Required	✓ Required	✓ Required	✓ Required	✓ Required (up to end user)	Not included (TTW excluded)
ISCC CORSIA	Optional	✓ Required (if >10% of total emissions)	✓ Required	✓ Required	✓ Required	✓ Required	✓ Required	✓ Required (up to aircraft operator)	Not included (TTW excluded)
RSB (Global)	✓ Required (capital goods)	✓ Required (market- or location-based)	✓ Required	✓ Required	✓ Required	✓ Required	✓ Required	✓ Required	Not included (TTW excluded)
EPA RFS (US)	Not required	✓ Required (total energy input-based)	Not required	✓ Required	Not required (unless biogenic source)	Not required (if within plant gate)	✓ Required	Not required (up to plant gate)	Not included (TTW excluded)

Figure 3-2 Illustrative comparison of lifecycle GHG accounting for an e-methanol pathway across certification frameworks

Overall, although lifecycle-based accounting principles are increasingly converging across schemes, important methodological differences remain in pathway specificity, operational-data requirements, and treatment of advanced fuel pathways. These differences may result in significantly different certified carbon-intensity values for identical fuels across regulatory systems.

3.3.1 Co-product allocation methods

Co-product allocation is one of the most influential methodological elements in lifecycle GHG accounting. Many sustainable fuel pathways generate multiple outputs simultaneously, including fuels, electricity, heat, chemicals, animal feed, or industrial byproducts. Certification systems, therefore, require methodologies to allocate emissions between the main fuel product and associated co-products.

This issue is particularly relevant for several emerging marine fuel pathways. For example, renewable hydrogen production through electrolysis generates oxygen as a co-product, while biofuel production pathways may simultaneously produce animal feed, electricity, heat, glycerol, biochar, or other marketable products. Similarly, biomass gasification and biorefinery systems often export surplus electricity or steam, and e-fuel production facilities may provide excess oxygen or recoverable heat. Depending on whether emissions are allocated using energy content, economic value, substitution (system expansion), or other approaches, the lifecycle GHG intensity attributed to the final marine fuel can vary substantially. Consequently, co-product allocation remains one of the largest sources of methodological variation across certification systems and fuel pathways.

Existing schemes apply different allocation approaches depending on regulatory objectives, pathway characteristics, and modelling philosophy. The choice of allocation method can significantly affect the certified carbon intensity (CI) of fuels, particularly for biofuels, waste-based fuels, and e-fuel pathways.

Under ISCC EU and the EU RED's approved schemes, co-product allocation is primarily based on energy content. Lifecycle emissions are distributed between fuel products and co-products according to their LHV. This approach is intended to provide consistency and comparability across pathways while avoiding excessive dependence on fluctuating market prices.

ISCC CORSIA follows a similar energy-allocation approach aligned with ICAO lifecycle methodologies for sustainable aviation fuels (SAF). Because SAF pathways frequently generate additional products such as naphtha, gases, or electricity, allocation rules are important for determining final lifecycle emissions.

RSB Global applies a more flexible methodology and may incorporate broader system-level considerations depending on the pathway. Compared with the EU RED, RSB Global generally places greater emphasis on reflecting actual environmental consequences and pathway-specific conditions.

California LCFS applies more pathway-specific allocation methodologies. Depending on the fuel pathway, LCFS may use energy allocation, displacement credits, or system-expansion approaches within GREET-based (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) lifecycle modeling. For example, excess electricity exports, renewable power generation, or carbon capture may influence pathway CI values through crediting mechanisms.

RenovaBio similarly incorporates co-product treatment within its lifecycle-efficiency modelling framework. Allocation outcomes directly affect the Energy-Environmental Efficiency Score and therefore influence CBIO generation.

EPA RFS relies more heavily on pathway-level lifecycle modelling and system-expansion logic rather than uniform operational allocation rules. The methodology evaluates overall lifecycle reductions relative to fossil-fuel baselines at pathway level.

A key implication is that identical fuel pathways may receive significantly different certified CI values under different allocation methods. Energy allocation generally provides greater methodological consistency and regulatory simplicity, while system-expansion and displacement approaches may better capture broader environmental effects but introduce greater modelling uncertainty and sensitivity to assumptions.

The treatment of co-products becomes particularly important for advanced marine fuels, including e-methanol, hydrogen-derived fuels, biofuels, and waste-based pathways, where

electricity exports, oxygen generation, captured carbon, or industrial byproducts may substantially affect lifecycle emissions.

3.3.2 Treatment of emission credits and avoided emissions

In addition to direct lifecycle emissions, several certification and regulatory schemes allow specific forms of emission credits or avoided-emission adjustments within GHG accounting methodologies. These mechanisms are intended to recognize emissions reductions associated with renewable electricity exports, carbon capture, waste utilization, or displacement of fossil-based products. However, the treatment of such credits differs significantly across schemes and can substantially influence certified carbon intensity values. This is illustrated in Table 3-4.

Table 3-4 Treatment of emission credits and avoided emissions across major schemes

Scheme	Types of credits / avoided emissions	Typical treatment
ISCC EU	Excess renewable electricity CCS/CCU (pathway-specific)	Allowed under specific approved pathways and methodological conditions
ISCC CORSIA	SAF lifecycle reduction credits Limited treatment of additional avoided emissions (landfill & recycling emissions credits)	Conservative treatment under ICAO lifecycle methodology
RSB Global	Renewable electricity export Co-product displacement CCS-related reductions	Includes pathway-specific avoided-emission considerations
California LCFS	Electricity export credits CCS/CCU Renewable energy substitution	Explicitly incorporated into GREET-based CI calculations
RenovaBio	Lifecycle efficiency improvements Limited indirect avoided-emission treatment	Reflected through Energy-Environmental Efficiency Score
EPA RFS	Lifecycle reductions relative to fossil baseline	Incorporated through pathway-level regulatory modelling
IMO MEPC.391(81)	Soil carbon accumulation credits CCS-related emission adjustments Excess renewable electricity (RFNBO-related pathways)	Included as pathway-specific lifecycle accounting adjustments within WtW methodology

Under ISCC EU, avoided emissions may be credited under specific conditions, particularly where renewable electricity is exported from the production process or where carbon capture and utilization/storage (CCU/CCS) is integrated into approved fuel pathways. However, the treatment is generally conservative and restricted to predefined methodological rules.

ISCC CORSIA applies ICAO-approved lifecycle accounting methodologies for sustainable aviation fuels (SAF). The framework primarily evaluates direct lifecycle greenhouse gas reductions relative to conventional jet fuel baselines and adopts a comparatively conservative approach toward additional avoided-emission credits beyond standardized SAF accounting methodologies.

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RSB Global applies more flexible lifecycle-assessment approaches and may include avoided emissions associated with renewable electricity exports, co-product displacement effects, or carbon-capture integration, which were justified within pathway-level assessment.

California LCFS applies one of the most extensive lifecycle adjustment and pathway crediting frameworks among existing systems. GREET-based pathway modeling may incorporate displacement credits associated with renewable electricity exports, CCS-related emission reductions, renewable hydrogen integration, and substitution effects relative to fossil-based electricity or fuels. These pathway-specific adjustments can substantially reduce calculated carbon intensity values and increase LCFS credit generation.

RenovaBio primarily reflects avoided emissions indirectly through lifecycle efficiency scoring rather than through extensive pathway-level credit adjustments.

EPA RFS incorporates avoided emissions mainly through pathway-level lifecycle modeling relative to fossil-fuel baselines, rather than explicit operational credit mechanisms.

A major challenge across all schemes is the risk of over-crediting or double counting. Avoided emissions associated with renewable electricity, CCS, waste utilization, or displaced fossil products may potentially be claimed simultaneously across multiple regulatory or voluntary systems if boundaries and ownership rules are not clearly defined.

The treatment of avoided emissions is particularly important for emerging marine fuels such as e-methanol, e-ammonia, hydrogen-based fuels, and carbon-capture-integrated pathways, where renewable electricity sourcing and the utilization of captured carbon may dominate lifecycle performance. For maritime SFCS, in particular when emissions accounting move between domestic and international shipping accounts, clear rules will be required regarding ownership of emission reductions, eligibility of avoided-emission credits, interaction with external carbon markets, and prevention of double claiming across jurisdictions and compliance systems.

3.3.3 Treatment of methane slip and fugitive emissions

Methane slip has become an increasingly important issue in lifecycle GHG accounting, particularly for LNG, bio-LNG, and synthetic methane-based fuel pathways. Methane has a significantly higher global warming potential (GWP) than carbon dioxide over both 20-year and 100-year time horizons. As a result, even relatively small methane releases during fuel production, transport, storage, or combustion can substantially affect lifecycle carbon intensity values.

Methane-related emissions may occur across multiple lifecycle stages, including upstream natural gas extraction and processing, fuel liquefaction, transport and bunkering, onboard storage, and engine combustion. In maritime applications, methane slip from dual-fuel LNG

engines is considered one of the most important contributors to lifecycle uncertainty for LNG pathways.

Table 3-5 Treatment of methane emissions and methane slip across major schemes

Scheme	Methane treatment
ISCC EU	Included in lifecycle accounting
ISCC CORSIA	Included for applicable pathways
RSB Global	Explicit lifecycle treatment
California LCFS	Detailed methane accounting
RenovaBio	Included in lifecycle modelling
EPA RFS	Included in lifecycle threshold modelling

Across existing schemes, methane emissions are generally incorporated within lifecycle GHG accounting where relevant to gaseous fuel pathways, biogas systems, natural gas supply chains, or methane-based fuels. ISCC EU, ISCC CORSIA, RSB Global, RenovaBio, and EPA RFS typically include methane-related emissions within broader lifecycle calculations rather than through dedicated methane-slip methodologies. In contrast, California LCFS applies more detailed methane-accounting approaches, including upstream methane leakage, pathway-specific assumptions, and operational modeling associated with natural gas production, transport, and fuel use. Compared with other schemes, LCFS places greater emphasis on methane as a key determinant of pathway carbon intensity and credit generation. Overall, differences in methane treatment, leakage assumptions, and GWP methodologies can lead to significant variation in lifecycle emissions results, particularly for LNG, bio-LNG, and synthetic methane-based fuel pathways. A summary is provided in Table 3-5.

For maritime SFCS, methane-slip treatment will be particularly important for LNG-, bio-LNG-, and e-methane-fueled vessels, where onboard combustion emissions may significantly affect WtW performance. Inherently, bio-LNG and e-methane would have lower lifecycle emissions than fossil LNG. However, the absolute value of methane slip emissions would be similar due to methane's high global warming potential, regardless of whether the methane-based fuels are fossil-based. Methane slip varies substantially across engine technologies, operating loads, and vessel types, especially between low-pressure and high-pressure dual-fuel engines. In addition to onboard emissions, upstream methane leakage associated with liquefaction, bunkering, storage, and international fuel transport may further influence lifecycle emissions. Maritime certification systems may therefore require engine-specific methane-slip factors, vessel operational profiles, bunkering-chain emissions accounting, and harmonized upstream leakage assumptions to ensure consistent

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comparison between gaseous and non-gaseous marine fuel pathways under international regulatory frameworks.

Fugitive emissions from fuel loss (other than methane) before the energy converter are currently set to zero under the 2024 IMO LCA guidelines and are subject to continuous review[1].

3.4 Data requirements, verification, and uncertainty considerations

Lifecycle GHG accounting under existing sustainable fuel certification systems is highly dependent on data quality, traceability, and verification procedures. As certification increasingly shifts from conventional product verification toward pathway-specific emissions accounting, reliable data management has become a central component of system credibility.

Across ISCC EU, ISCC CORSIA, RSB, California LCFS, RenovaBio, and EPA RFS, lifecycle calculations generally require a combination of primary operational data and secondary emissions factors. Primary data commonly include electricity consumption, fuel use, transport distance, feedstock sourcing, process efficiency, and production output. Secondary data are typically derived from approved databases, default values, or regulatory emissions models where direct operational data are unavailable. Table 3-6 shows a summary of data requirements across lifecycle stages.

Table 3-6 Typical data requirements across lifecycle stages

Lifecycle stage	Typical data requirements	Verification approach
Feedstock production / collection	Feedstock origin, agricultural inputs, collection records	Supplier documentation and traceability checks
Transport and logistics	Transport mode, distance, fuel consumption	Bills of lading, transport records
Fuel processing / conversion	Electricity use, fuel consumption, production yield	Metering systems, utility bills, process records
Electricity sourcing	Grid mix, renewable electricity contracts	Energy certificates and contractual evidence
Distribution and storage	Fuel transfer and storage records	Chain-of-custody verification
Fuel use / combustion	Fuel characteristics and pathway assumptions	Regulatory pathway verification

[1] IMO (2024). 2024 Guidelines on life cycle GHG intensity of marine fuels (MEPC.391(81)). Available: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.391(81).pdf, Accessed: Apr 2026

Most schemes require third-party verification of reported operational data and chain-of-custody documentation. ISCC EU, ISCC CORSIA, and RSB place strong emphasis on mass balance systems, traceability records, and audit consistency across supply chains. California LCFS and RenovaBio apply more detailed pathway verification because lifecycle emissions directly determine credit generation and economic value.

A major challenge across all systems is uncertainty associated with operational variability, data availability, and methodological assumptions. Key uncertainty sources commonly include electricity carbon intensity, methane leakage, feedstock classification, transport logistics, co-product allocation, and process efficiency. These uncertainties may significantly affect certified carbon-intensity values, particularly for RFNBOs, e-fuels, LNG pathways, and waste-based fuels.

Data integrity also becomes increasingly challenging in international supply chains involving multiple intermediaries, cross-border fuel movements, and digital sustainability registries. Several documented fraud cases across existing systems have involved falsified feedstock declarations, inaccurate lifecycle data, and inconsistencies between physical fuel flows and reported sustainability attributes.

3.5 Implications for maritime SFCS

For maritime SFCS, data and verification requirements will need to address sector-specific challenges that are not fully captured in existing fuel certification systems. First, marine fuels are frequently bunkered in one jurisdiction and consumed in another, creating difficulties in maintaining a continuous chain-of-custody and avoiding double claiming of sustainability attributes across ports and regulatory systems. Verification frameworks may therefore require linkage between bunker delivery notes (BDNs), fuel sustainability certificates, port bunkering records, and IMO Data Collection System (DCS) or EU Monitoring, Reporting, Verification (MRV) reporting data.

Second, operational emissions for marine fuels may vary significantly depending on vessel type, engine technology, voyage profile, and operating conditions. For LNG- and methane-based fuels, methane slip may differ substantially between low-pressure and high-pressure dual-fuel engines and between deep-sea and short-sea operational profiles. Maritime SFCS may therefore require engine-specific emission factors and onboard monitoring data rather than relying solely on pathway-average assumptions.

Third, international bunkering supply chains involve multiple intermediaries, blending operations, storage terminals, and ship-to-ship transfers, increasing traceability complexity compared with fixed land-based distribution systems. Verification may therefore require integration of mass-balance systems with digital fuel-tracking platforms, cargo transfer records, AIS-based voyage tracking, and terminal-level inventory reconciliation.

Finally, electricity-intensive marine fuels such as e-methanol, e-ammonia, and hydrogen-derived fuels introduce additional verification requirements associated with renewable electricity sourcing, temporal matching, and geographic correlation between electricity generation and fuel production. Existing certification systems only partially address these issues, but they are likely to become critical for maritime pathways where upstream electricity emissions dominate overall lifecycle performance.

4 RIGOR OF SCOPE (ENVIRONMENTAL, SOCIAL, ECONOMIC)

This section covers sustainability aspects beyond GHG emissions. Environmental, social and economic aspects are considered. These can be quantified via life cycle impact assessment (LCIA) methods such as ReCiPe, a widely used framework that translates inventory emissions and resource use into environmental impact indicators at both midpoint and endpoint levels, including damage to ecosystems, human health, and resource availability[1]. However, under sustainability certification schemes, these aspects are typically considered qualitatively. Under the RSB, public comments are sought as part of the certification[2], where concerned parties can raise concerns about the applicant's operational sustainability through a dedicated email address.

4.1 Mandatory and scheme-specific sustainability requirements

Some sustainability requirements are mandated under the sustainability directive, while some are imposed by the sustainability schemes. For example, RSB may have stricter sustainability requirements than the ISCC.

4.1.1 ISCC

ISCC EU is the scheme recognized under EU RED for biofuels, ensuring compliance with the EU's legal sustainability requirements. ISCC PLUS is a voluntary extension that covers sectors and materials beyond EU transport fuel regulation (e.g., food, feed, chemicals, bio-based products)[3]. ISCC PLUS applies the same core sustainability principles, but certain elements like GHG savings are voluntary rather than mandatory. ISCC's framework is built on 6 principles covering environmental, social, and governance aspects. Principle 1 addresses protection of land with high biodiversity or carbon stock (no conversion of primary forest, peatland, etc.). Principle 2 ensures environmentally responsible production – conserving soil, water and air quality. Principles 3 and 4 cover social sustainability: safe working conditions (occupational health and safety) and respect for human and labor rights, including community relations. Principle 5 requires compliance with land rights, laws, and international treaties. Principle 6 promotes good management practices and continuous improvement, including economic stability of the operator (e.g. maintaining basic economic documentation and a business plan). In practice, ISCC EU certification mandates immediate compliance with RED's core criteria (land-use and GHG thresholds) and uses a continuous improvement approach for additional criteria: farms/operations must meet all

[1] SimaPro (n.d.). Understanding the ReCiPe impact assessment method. Available: https://simapro.com/insights/understanding-the-recipe-impact-assessment-method/, Accessed: Jun 2026
[2] RSB (n.d.). Call for Public Comments. Available: https://rsb.org/certification/call-for-public-comments/, Accessed: Jun 2026
[3] ISCC (2023). ISCC PLUS Version 3.4.2. Available: https://iscc-system.org/wp-content/uploads/dlm_uploads/2026/03/ISCC-PLUS.pdf, Accessed: Jun 2026

immediate requirements from Principles 2–6 and then achieve short-term and mid-term improvements over 3–5 years on more advanced practices.

ISCC has also developed ISCC CORSIA for Sustainable Aviation Fuel under ICAO's CORSIA program. ISCC CORSIA requires compliance with CORSIA's sustainability themes for fuel to be deemed "CORSIA eligible". ISCC also offers an enhanced ISCC CORSIA PLUS option, which applies the full ISCC Principles 1 to 6 for stronger sustainability oversight. However, under CORSIA, some social criteria are addressed through government attestations or reporting rather than full on-site audits.

4.1.2 ICAO CORSIA – Sustainability Framework for Aviation Fuels

The International Civil Aviation Organization's CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) includes a dedicated sustainability framework to ensure that alternative aviation fuels (SAF) used for emissions reduction claims are genuinely sustainable. After extensive negotiation, ICAO adopted 12 sustainability themes encompassing environmental, social and economic principles[1]. These themes and criteria form an eligibility filter for fuels: only SAF meeting these criteria can be counted toward CORSIA's CO_2 offsetting targets. In summary, the CORSIA criteria require that SAF: (1) achieves a net GHG reduction of at least 10% compared to conventional jet fuel on a life-cycle basis (in practice much higher reductions are expected, and lifecycle accounting must include indirect land-use change); (2) is not produced from biomass obtained from land with high carbon stock or high biodiversity value after January 1, 2008 (no conversion of primary forests, wetlands, peatlands, etc.); (3) does not cause significant degradation of soil, water, or air – requiring good practices to protect water quality, maintain soil health, and avoid air pollution (e.g. restrictions on open burning and control of emissions); (4) respects conservation values by protecting ecosystems and biodiversity not already covered by the land-use prohibition; (5) sustainably manages waste and chemicals to prevent pollution; (6) upholds human and labor rights (no forced or child labor, decent working conditions), (7) respects land use rights and water rights of local communities (including indigenous peoples' rights and Free, Prior and Informed Consent (FPIC) for land use changes), (8) contributes to local social and economic development, and (9) does not endanger food security. Each theme has detailed criteria; for example, under Human and labor rights, there are criteria aligned with fundamental International Labor Organization (ILO) conventions, and under Local development the fuel production should benefit local communities or at least do no harm.

CORSIA's sustainability framework is implemented through approved certification schemes. It is noteworthy as the first United Nations-agreed (UN-agreed) standard defining what

[1] ICAO (2026). Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Available: https://www.icao.int/CORSIA, Accessed: Jun 2026

"sustainable fuel" means across a broad range of aviation issues. However, some criteria rely on host state attestations or operator reporting, which makes enforcement less direct than under stricter voluntary schemes. Nevertheless, CORSIA provides a useful reference for other sectors, including maritime fuels.

4.1.3 RSB – Roundtable on Sustainable Biomaterials

The RSB is a multi-stakeholder sustainability standard widely regarded as one of the most rigorous frameworks for bio-based fuels and materials. RSB's system is built on 12 Principles & Criteria that collectively address the three pillars of sustainability: environmental, social, and economic (legal/management) aspects. The RSB Principles include legality (Principle 1), planning and continuous improvement (2), greenhouse gas emissions (3), human and labor rights (4), rural and social development (5), local food security (6), conservation of biodiversity and ecosystems (7), soil health (8), water management (9), air quality (10), use of inputs and waste management (11), and land rights (12)[1]. These criteria form a comprehensive sustainability umbrella covering many aspects from GHG lifecycle reductions to community impacts and have been peer-reviewed and aligned with global best practices.

Under RSB certification, operators must implement a sustainability management system and meet minimum requirements immediately, with some criteria designated as progress requirements to be achieved over time (typically within 3 years). This allows continuous improvement while still ensuring an initial high bar of performance. RSB requires robust lifecycle GHG accounting (Principle 3) and imposes GHG reduction thresholds that align with or exceed regulatory baselines (e.g. for transport biofuels, at least 50–65% lower emissions than fossil fuel, depending on the production date and fuel type, per EU RED values). It explicitly protects high conservation value areas and biodiversity (Principle 7) by prohibiting the use of biomass from land converted after a cutoff date (e.g. no feedstock from primary forests, wetlands or peatlands converted after January 2008, similar to EU and CORSIA rules) and by requiring ecosystem conservation plans. RSB also uniquely includes social development (Principle 5) and food security (Principle 6) criteria – operators must assess and mitigate any risk of their feedstock operations curtailing local food access, and wherever possible, contribute to rural development and poverty reduction. Labor rights and worker safety are emphasized (Principle 4), aligning with ILO conventions on no child/forced labor, freedom of association, non-discrimination, and providing safe working conditions with proper training and protective measures. Communities and land users are protected through requirements for transparent stakeholder engagement, respect for land tenure rights and FPIC for new land acquisitions (Principle 12). RSB's standard is approved for EU RED compliance and was one of the first schemes approved by ICAO for CORSIA SAF

[1] RSB (2023). STD-01-001: RSB Principles & Criteria. Available: https://rsb.org/wp-content/uploads/2020/06/RSB-Principles-Criteria-STD-01-001-v4-1.pdf, Accessed: Jun 2026

certification. In practice, RSB offers options to certify fuels either just to the CORSIA criteria or to CORSIA and full RSB standards – the latter ensuring more social and environmental safeguards. For the maritime sector, RSB has launched a Sustainable Marine Fuel Platform to adapt and promote its framework for shipping fuels, facilitating cross-sector learning so that marine fuel production and use "is developed in a consistent, just and sustainable manner".

4.1.4 California Low Carbon Fuel Standard (LCFS)

As a regulatory program rather than voluntary certification scheme, California's LCFS mandates lifecycle carbon intensity reductions in transportation fuels used in California[1]. The core of LCFS is performance-based GHG reduction, where fuel producers must calculate the full lifecycle emissions of their fuels using CA-GREET models and progressively lower the carbon intensity to meet annual targets. Historically, the LCFS primarily addressed climate impact, with indirect effects like ILUC accounted for in fuel pathways' carbon intensities. In late 2024, the California Air Resources Board (CARB) approved major LCFS amendments that introduce broad sustainability requirements for fuels, especially crop-based biofuels.

Under the new rules[2], biomass feedstocks must come from land cultivated before 2008 to prevent recent deforestation or native land conversion. Certification must also cover environmental, social and economic sustainability criteria, including biodiversity, soil quality, water quality and pollution management. The LCFS is phasing these requirements in gradually. Basic attestations for non-waste biomass begin in 2026, no-deforestation certification is required by 2028, and full certification with chain of custody tracking is expected by 2031. CARB plans to accept existing EU recognized schemes such as ISCC EU and RSB. This effectively transposes the rigor of voluntary certification schemes into California's regulatory context.

4.1.5 RenovaBio

RenovaBio is Brazil's National Biofuels Policy, established to reduce the carbon intensity of fuels used in the transport sector and to recognize the contribution of biofuels to national decarbonization[3]. Unlike ISCC or RSB, it is a regulatory and market-based certification

[1] CARB (2025). Overview of the Low Carbon Fuel Standard. Available: https://ww2.arb.ca.gov/sites/default/files/2025-11/LCFS%20Basics_post11-20-25_final.pdf, Accessed: Apr 2026

[2] CARB (2025). Updates to the Low Carbon Fuel Standard and the Role of Certification. Available: https://iscc-system.org/wp-content/uploads/add-from-server-reloaded/Update-on-the-Low-Carbon-Fuel-Standard-LCFS-and-the-Role-of-Certification-%E2%80%93-Carmen-Meialua-Air-Pollution-Specialist-California-Air-Resources-Board-CARB-US.pdf, Accessed Jun 2026

[3] Government of Brazil (2026). RenovaBio. Available: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/renovabio-1/renovabio-ingles, Accessed: Apr 2026

framework under which biofuel producers and importers may voluntarily obtain a Certificate of Efficient Biofuel Production or Importation. Once certified, they can generate Decarbonization Credits (CBIOs), while fuel distributors must meet annual mandatory decarbonization targets by acquiring and retiring CBIOs. The central sustainability metric is therefore the Energy-Environmental Efficiency Rating, which is derived from the life-cycle carbon intensity calculated through RenovaCalc. Lower-carbon production routes generate a stronger economic signal because the number of CBIOs available per unit of biofuel is linked to the certified performance and eligible production volume.

RenovaBio does, however, include important biomass eligibility safeguards. The current ANP certification regulation requires eligible biomass to be traceable and excludes biomass from areas where native vegetation has been suppressed from the RenovaBio legal cut-off date[1]. For biomass produced in Brazil, the rural property must also have an active or pending Rural Environmental Registry (Cadastro Ambiental Rural, CAR), while oil-palm feedstock must comply with Brazil's agro-ecological zoning rules for palm expansion. These requirements give RenovaBio a relatively strong climate and land-use filter, especially for domestic agricultural feedstocks. Nevertheless, its scope is narrower than ISCC or RSB because it does not provide a detailed certification standard for biodiversity management, soil and water stewardship, labour rights, worker safety, community engagement or food security. For this reason, RenovaBio is more like a robust carbon-intensity and eligibility certification system, rather than a comprehensive environmental, social and governance sustainability scheme.

4.2 Environmental Criteria

Scope and enforcement approach vary across different schemes in terms of environmental criteria. Biodiversity and land-use protection are rigorous across ISCC, RSB and CORSIA. ISCC and RSB both categorically ban sourcing from recently deforested or high-carbon-stock land, using 2008–2009 as a cutoff. They require identification of sensitive areas and maintenance of ecological corridors and buffer zones. RSB, in particular, goes beyond no conversion by expecting active conservation: producers should manage and protect any High Conservation Value areas on their land, for example, set aside land for conservation or maintain biodiversity action plans[2]. ISCC's baseline for Principle 1 aligns with legal

[1] ANP (2025). ANP Resolution No. 984, of June 16, 2025 – Official Gazette of June 17, 2025. Available: https://leis.org/institucionais/br/anp/lei/resolucao/2025/984/resolucao-n-984-2025-regulamenta-a-certificacao-da-producao-ou-importacao-eficiente-de-biocombustiveis-de-que-trata-o-art-18-da-lei-n%C2%BA-13576-de-26-de-dezembro-de-2017-e-o-credenciamento-de-firmas-inspetoras, Accessed: Apr 2026

[2] RSB (2025). STD-01-001: RSB Principles & Criteria. Available: https://rsb.org/wp-content/uploads/2024/06/RSB-Principles-and-Criteria.pdf, Accessed: Apr 2026

deforestation bans (making it acceptable under EU RED and CORSIA)[1], and ISCC PLUS extends that globally. LCFS, which historically did not concern itself with land sourcing beyond ILUC, is now catching up – by 2028, feedstocks must be certified deforestation-free. This closes a major gap that existed in many regulatory schemes outside the EU. However, until those provisions fully kick in (2028–2030), there is a transitional risk: some crop-based fuels could still enter LCFS without comprehensive biodiversity checks. The phased approach of attestations, followed by full certification by 2031, is designed to give industry time to adapt, but it also means the rigor of enforcement in LCFS will lag behind that of the voluntary schemes for a few more years.

On climate performance on GHG, the LCFS to some extent is the most stringent in outcome with annually tightening CI targets and a direct economic penalty for high-carbon fuels. It effectively forces continuous improvement in carbon efficiency. But LCFS itself does not provide a qualitative threshold per fuel. For example, it's possible to use a fuel that is only 20% better than diesel and still generates some credits, especially in early years. By contrast, ISCC and RSB enforce entry thresholds that if a biofuel doesn't reach the minimum GHG savings of 50–65%, depending on context, it cannot be certified as sustainable under those schemes[2]. RSB's threshold aligns with the EU RED and even foresees higher percentages for future operations, ensuring that only substantially decarbonized fuels qualify. CORSIA's 10% minimum GHG reduction was intentionally set low as a safeguard. In practice, airlines would prefer fuels with far greater reductions, and any fuel with large indirect emissions would likely fail to deliver cost-effective carbon savings and thus be nonviable under CORSIA's lifecycle accounting.

Although all schemes consider full life-cycle GHG accounting, their levels of rigor differ. LCFS and RSB require detailed modeling and verification of actual data every year; ISCC/RSB require meeting fixed reduction benchmarks; CORSIA requires a modelled assessment including ILUC, with at least a modest improvement. For marine fuels, where lifecycle CO_2 will be scrutinized under IMO lifecycle guidelines, these schemes may provide a ready blueprint for how to do robust carbon accounting.

On other environmental factors – soil, water, air, and chemicals, RSB and ISCC show comprehensive coverage. Both promote good agricultural practices: e.g. no burning of crop residues which protects soil carbon and prevents smoke pollution, measures to prevent soil erosion and nutrient depletion, rational fertilizer use, protection of watercourses through buffer zones, etc. RSB breaks these out into separate principles of Soil, Water and Air, underlining their importance. ISCC combines them under environmentally responsible

[1] ISCC (2025). ISCC EU 202-4 Forest Biomass: ISCC Principle 1. Available: https://iscc-system.org/download/iscc-eu-202-4-forest-biomass-iscc-principles-2-6/?tmstv=1782462424, Accessed: Apr 2026

[2] RSB (2025). STD-01-001: RSB Principles & Criteria. Available: https://rsb.org/wp-content/uploads/2024/06/RSB-Principles-and-Criteria.pdf, Accessed: Apr 2026

production and includes detailed criteria such as requiring an Environmental Impact Assessment for new cultivation to evaluate impacts on soil, water, air, and climate. CORSIA incorporated these aspects explicitly in Themes 4–8, meaning any CORSIA scheme must demonstrate, for example, that soil health is not significantly harmed and that air quality is protected. Interestingly, if an operator meets ISCC's existing Principles 1 and 2 major requirements, they would, by extension, meet CORSIA's soil, water, air, conservation, and waste criteria. This indicates ISCC's criteria in those areas were already largely aligned with what CORSIA expects.

LCFS's new inclusion of these factors is a significant strengthening of the policy. Requiring certified compliance with criteria on biodiversity, soil, water and pollution means that in a few years, a corn ethanol plant or a tallow biodiesel producer selling into California must adhere to similar on-farm environmental practices as one selling into Europe via ISCC or RSB. The challenge will be implementation and oversight. CARB will rely on third-party certifiers and auditors essentially outsourcing the environmental monitoring to certification bodies. The fact that CARB is only approving schemes recognized by the EU or schemes meeting strict criteria is reassuring in this regard.

RenovaBio's environmental criteria are concentrated on life-cycle GHG performance and biomass eligibility. Its strongest environmental element is the certified carbon-intensity calculation through RenovaCalc, which covers the agricultural, industrial and distribution phases of biofuel production and converts the result into an Energy-Environmental Efficiency Rating. The system also applies land-use eligibility checks: eligible biomass must not originate from areas with native vegetation suppression after the RenovaBio cut-off date, domestic biomass must be linked to a rural property with active or pending CAR status, and oil palm must be located within areas considered suitable under the national agro-ecological zoning framework. These provisions provide a meaningful deforestation and land-use safeguard, but they are less comprehensive than ISCC or RSB. In practice, RenovaBio relies more on Brazilian environmental law, geospatial eligibility checks, traceability and LCA-based carbon incentives than on a broad farm-level environmental management standard.

In summary, on environmental criteria, RSB stands out as the most exhaustive and stringent covering even niche issues like invasive species management in Principle 7, or banning highly hazardous pesticides in Principle 11, while ISCC covers all key areas solidly, meeting regulatory requirements and beyond. CORSIA sets a broad baseline ensuring no major aspect is overlooked, though some details remain flexible. LCFS is evolving from a pure carbon metric to a more rounded sustainability program, but as of now its enforcement of non-GHG criteria is still in the early stages (full effect by 2030). RenovaBio occupies a different position: it is strong on life-cycle carbon intensity, native vegetation conversion safeguards and biomass traceability, but comparatively weak on detailed environmental

management beyond land eligibility and legal compliance. For maritime fuels, which can involve diverse feedstocks, these environmental safeguards are crucial to prevent simply shifting emissions. The existing schemes provide a ready toolkit to evaluate marine fuel supply chains against these criteria, and new initiatives like RSB's marine fuel platform aim to ensure exactly that consistency.

4.3 Social and Labor Criteria

All reviewed schemes acknowledge that sustainable fuels must respect human rights and labor standards, but their approach to social criteria differs in depth. RSB is often regarded as the gold standard for social issues: its Principles on Human and Labor Rights, Rural Development, Food Security, and Land Rights comprehensively cover the spectrum from worker-level conditions to community and macro-level impacts. RSB requires on-site social impact assessments and stakeholder consultations for new projects, ensuring the voices of workers and communities are heard. Its certification process typically involves interviews with staff and locals, document checks (contracts, age verification, wage records), and field observations. Because of this, RSB has a strong reputation for safeguarding workers and communities. In addition, RSB pushes certificate holders to contribute positively, not just avoid negatives: Principle 5 (Rural & Social Development) and Principle 6 (Food Security) encourage operators to create local benefits and avoid displacing food production. This is an area where RSB's rigor clearly exceeds that of ISCC and most regulatory schemes.

ISCC EU and PLUS cover the essential "do no harm" social elements: no forced or child labor, no gross labor abuses, safe working conditions, and respect for land rights. These are mostly framed as compliance with laws and basic ILO standards. ISCC requires signing a self-declaration on social practices and adherence to applicable labor legislation. On worker safety, ISCC is quite explicit with a dedicated principle ensures auditors check for training, safety equipment, and accident records. ISCC's strength lies in ensuring a baseline of decent practice: you cannot be ISCC-certified if you have land conflicts or violate labor laws, which is a critical safeguard for maritime fuel sourcing that filters out entities potentially in violation of the law. For companies aiming higher, ISCC PLUS allows optional integration of additional modules or criteria.

The ICAO CORSIA framework clearly emphasizes the importance of social issues – dedicating Themes 10--14 to human rights, labor rights, land and water use rights, local development, and food security[1]. For some themes such as human rights and land rights, CORSIA relies mainly on national attestations, implying trust in domestic legal frameworks. This may create gaps where laws exist but are weakly enforced. For food security and local

[1] ICAO (2025). CORSIA Sustainability Criteria for CORSIA Eligible Fuels. Available: https://www.icao.int/sites/default/files/environmental-protection/CORSIA/Documents/CORSIA%20Eligible%20Fuels/ICAO-document-05-Sustainability-Criteria-June-2025.pdf, Accessed: June 2026

development, producers are mainly required to report actions. ISCC follows CORSIA's approach when operating as a CORSIA Certification Scheme, while RSB can go further by applying its full principles, making social safeguards more enforceable.

Considering California's LCFS, LCFS amendments specifically mention social and economic sustainability criteria needing certification. CARB will not define those criteria itself, but by approving only schemes with strong social components, it ensures issues like labor rights and land rights are checked. This is a big step in a jurisdiction like the U.S., where historically fuel regulations didn't incorporate overseas labor or land use ethics. However, how rigorous this will depend on the scheme used: if a weaker scheme were approved, it could leave gaps. Only the criteria prohibiting deforestation are mandatory by 2028, whereas other social criteria may effectively remain voluntary until full certification is enforced. The phased rollout with no full certification until 2031, might indicate caution to avoid disrupting feedstock supply too quickly.

RenovaBio has limited explicit social and labor criteria. Social and labor safeguards are therefore mainly indirect, through compliance with Brazilian law and the ordinary regulatory environment applicable to agricultural and industrial operators.

To summarize social aspects: RSB is the most rigorous and comprehensive, ensuring not just absence of negatives (rights violations) but presence of positives (community benefits, food security measures). ISCC provides solid safeguards on fundamental rights and safety, which cover the basics effectively. CORSIA sets a broad expectation for good social performance but with a lighter touch in verification for certain elements . LCFS is moving from virtually no social criteria to a system that will, via certifications, cover similar ground to ISCC/RSB; RenovaBio does not explicitly include social and labor criteria, because its certification logic is centered on carbon intensity, eligible biomass, and marketable CBIO.

For marine fuels, which can be produced from similar feedstocks e.g. palm oil, used cooking oil, municipal wastes, algae, etc., it will be crucial to apply these social criteria to avoid, for instance, bunkering ships with biofuels at the cost of worker exploitation in supply chains. The shipping industry, under pressure to decarbonize, also faces scrutiny to ensure its solutions are ethically and socially responsible – hence adopting or referencing these schemes in maritime fuel standards is highly recommended.

4.4 Economic Criteria

Sustainability schemes also include criteria that ensure the economic viability and governance of certified operations. This is sometimes overlooked, but it is important: a project that collapses financially or is mismanaged can lead to indirect sustainability failures, such as abandonment of plantations or inability to maintain environmental equipment. Both ISCC and RSB explicitly incorporate management system requirements and continuous improvement. ISCC's Principle 6 on Good Management and Continuous

Improvement requires producers to have basic business documentation and planning. It's essentially a check that the operation is run professionally and is committed to improving sustainability over time. ISCC's continuous improvement model is pragmatic, especially for small farmers who may need time and capacity building to adopt more advanced practices. However, this also means that rigor is time-phased: an ISCC certificate holder may still be working on certain improvements, with auditors checking progress in subsequent audits.

RSB's approach is similar in spirit: Principle 2 on Planning, Monitoring & Continuous Improvement requires a robust sustainability management system. Operators must identify sustainability risks, monitor indicators, and engage in an iterative improvement process. RSB also sets certain criteria as progress requirements to be met over a 3-year timeline. This ensures economic practicality, especially for new technologies or smaller operators, without compromising the end goal. Traceability and anti-fraud measures are also important governance features. ISCC and RSB both apply strict chain of custody rules to ensure that sustainability claims are backed by certified product flows.

California's LCFS does not evaluate the producer's management in the same way. However, its annual verification of fuel pathway data requires companies to maintain clear records and data systems.

RenovaBio is comparatively strong on economic and governance criteria because the entire scheme is built around a market mechanism. Certified producers and importers can generate CBIOs in proportion to the certified biofuel volume and the Energy-Environmental Efficiency Rating, while fuel distributors face mandatory annual decarbonization obligations. This creates a direct economic reward for lower-carbon and more efficient biofuel production without imposing a fixed volumetric mandate on each producer. The certification process also requires ANP-accredited inspection firms, documentation of the data used to calculate the efficiency rating and eligible volume, annual monitoring, traceability of eligible biomass and retention of supporting documentation. However, RenovaBio's economic strength lies mainly in its carbon credit incentive structure, not in a comprehensive environmental, social, and governance (ESG) management standard like ISCC or RSB.

One area where economic considerations are explicitly addressed is food security (Principle 6 of RSB). That is socio-economic, but it also ties into global economic equity. Only RSB really addresses it directly. ISCC and LCFS address it indirectly by favoring waste/residue feedstocks, which, by their nature, do not compete with food.

Continuous improvement and adaptability are worth noting as strengths of these schemes. ISCC and RSB are periodically updated to reflect new knowledge and policy changes, including EU RED requirements, low ILUC risk biomass and updated GHG thresholds.

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4.5 Strengths and Gaps

In comparing the schemes, a few notable points stand out:

- **RSB's breadth vs. others' focuses:** RSB offers the broadest and deepest coverage from climate to community, making it highly rigorous. Its strength is a holistic view of sustainability, and it is the only scheme that explicitly addresses food security. This is a valuable reference for the maritime SFCS. The trade-off is complexity and cost: RSB certification can be intensive, and not all fuel producers opt for it if not required. For maritime uptake, incentives or requirements may be needed to encourage the use of such a high-standard scheme.
- **ISCC's practicality and recognition:** ISCC is widely used in the biofuels industry, partly due to its pragmatic approach. It covers all critical issues sufficiently to satisfy regulators and stakeholders. It also uses existing legal compliance to lighten the load where possible. A potential gap in ISCC is that some of its ambitious criteria are not mandatory, which could allow some shortfalls initially.
- **CORSIA's global benchmark:** The CORSIA sustainability framework's biggest strength is its comprehensiveness at an international policy level. It sets a precedent that any sector-wide climate solution should integrate sustainability safeguards. For shipping, which operates globally like aviation, this is an important lesson. CORSIA's criteria mirror what civil society has called for in marine fuels as well. Issues such as avoiding biodiversity loss, not exacerbating air pollution, protecting workers, etc., are equally relevant to bunker fuels. The slight weakness in CORSIA is its enforcement mechanism, which, as discussed, relies on a mix of state and voluntary actions. Essentially, CORSIA sets the floor; individual airlines or fuel buyers can choose a higher ceiling.
- **LCFS's evolution:** California's move to integrate sustainability certification is a strong signal from a major market that regulating GHG emissions alone is not enough and sustainability must be multi-dimensional. One challenge is ensuring consistent verification across thousands of feedstock sources. Ensuring consistency and preventing fraud will require oversight. CARB's three-year reapproval of certification systems and its own verification program for fuel pathways should help maintain rigor.
- **RenovaBio's carbon-market orientation:** RenovaBio's main strength lies in translating verified life-cycle GHG performance into a tradable compliance asset. This makes it highly relevant for policy design because it demonstrates how certification, fuel carbon intensity and a crediting mechanism can be linked in a national fuel market. The key gap is that its sustainability scope is not holistic, possibly because it is a national scheme and other aspects can be left to other local regulations. RenovaBio has strong climate and land-use safeguards, but limited explicit criteria for labor, occupational safety, community impacts, food security, soil and water management.

While the schemes above were not originally devised specifically for marine fuels, their criteria largely apply to the feedstock production and fuel processing stages which are common across sectors. One consideration for maritime is downstream impact, for instance, the combustion of certain biofuels in ships might have different pollutant profiles such as particulate matter from bunker engines. MARPOL regulations cover some of the pollutants such as SO_X and NO_X. The comparison above suggests the frameworks are adaptable and these existing schemes are compatible and can provide a sustainability check for future marine fuels.

In terms of gaps, very few schemes, except partially CORSIA, explicitly address downstream use-phase emissions like black carbon from fuels in ships or planes. They focus on production. This is typically outside their scope, as it is regulated by environmental measures such as the IMO's regulations on ship emissions. The maritime sector might consider additional criteria or complementary measures to handle any unique use-phase concerns.

5 LOW-ILUC RISK REQUIREMENTS

ILUC occurs when growing biofuel crops displaces existing agricultural production elsewhere, potentially driving expansion of agriculture into natural areas (e.g., forests or peatlands) and causing additional GHG emissions. To safeguard the true climate benefits of biofuels, sustainability certification schemes have introduced measures to minimize ILUC risk[1]. Low ILUC risk certification typically involves demonstrating that feedstock production is additional: i.e. it increases biomass supply without diverting existing food/feed production or converting high-carbon land. This section compares how major schemes address ILUC risk, focusing on the International Sustainability & Carbon Certification (ISCC) family (ISCC EU, ISCC PLUS, ISCC CORSIA) and the Roundtable on Sustainable Biomaterials (RSB). We also briefly note the approaches of other voluntary schemes where relevant.

5.1 ISCC EU and ISCC PLUS

ISCC EU (EU-recognized for RED compliance) and ISCC PLUS (voluntary global scheme) have offer the dedicated "Low ILUC Risk Feedstock" add-on modules in documents ISCC 202-07 and ISCC PLUS 202-07 that farms or first-gathering points can receive certification for, in addition to the basic sustainability criteria [2] [3]. The modules were developed in line with EU RED requirements and the European Commission's Delegated Regulation (EU) 2019/807, which defines high-ILUC-risk feedstocks and sets criteria for certifying low-ILUC-risk biofuels. It is also aligned with ICAO's sustainability framework under CORSIA, which similarly outlines low-land-use-change (LUC) risk practices for sustainable aviation fuels (SAF). The ISCC 202-07 guidance stresses that low ILUC-risk feedstock must first meet all ISCC Principles 1–6 for sustainable agriculture before the additional ILUC criteria are applied.

5.1.1 Proof of low ILUC risk biomass

Under ISCC 202-07, producers must prove additional biomass production by one of two approved methods:

- **Yield increase on existing land:** Achieving a yield above the business-as-usual baseline on land already under cultivation, through improved practices or inputs. Only the incremental portion of yield, such as the amount above the historical average, qualifies as low-ILUC-risk output. A dynamic baseline yield is calculated

[1] ISCC (2024). ISCC 202-07 – Low ILUC Risk Feedstock V1.1. Available: https://iscc-system.org/wp-content/uploads/dlm_uploads/2026/03/ISCC-EU-202-07-Low-ILUC-Risk-Feedstock.pdf, Accessed: Apr 2026
[2] ISCC (2024). ISCC PLUS Add-on 202-07 Low ILUC-risk feedstock certification. Available: https://www.iscc-system.org/wp-content/uploads/2023/11/ISCC_PLUS_lowILUC_V1.0_July2023_Final.pdf, Accessed: Apr 2026
[3] ISCC (2024) ISCC 202-07 – Low ILUC Risk Feedstock V1.1. Available: https://iscc-system.org/wp-content/uploads/dlm_uploads/2026/03/ISCC-EU-202-07-Low-ILUC-Risk-Feedstock.pdf, Accessed: Apr 2026

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using recent years' data or regional statistics, and any production beyond that is deemed "additional" and eligible for low ILUC certification.

- **Cultivation on unused or degraded land:** Producers may bring previously unused, abandoned, marginal or degraded land into production, provided this does not displace existing crops or cause direct land-use change emissions. Evidence of land-use history is required to show that the land had no significant agricultural use in a defined period: no cropping or grazing since at least January 2008 for unused land; and that its use now does not incur direct land-use change emissions on high-carbon stock areas. Often, this includes demonstrating that the land was degraded or had low productivity and is now improved for biomass cultivation. Documentation may include maps, land records, carbon stock data and evidence of prior degradation or low productivity.

For either approach, ISCC requires that the increase in biomass supply is truly additional and not business-as-usual. Producers must undergo an additionality assessment, including a financial attractiveness test and/or barrier analysis. They must show that the yield improvements or land activation would likely not have occurred without the incentive of biofuel demand or sustainability-driven support. For example, a financial test might confirm that the chosen agricultural intervention, such as a new crop, inputs, double cropping, etc., was not already economically attractive on its own. Non-financial barriers, such as technical, knowledge, and risk factors, should also be documented to show that the measure goes beyond common practice.

Both approaches must also comply with ISCC's regular land criteria, such as no deforestation post-2008, no draining of peatlands, etc., and ensure the project has no direct LUC emissions. Auditors will verify past yield records, crop journals, receipts, maps and satellite data to ensure that the claimed additional biomass is real and not due to temporary weather conditions or misreported historical yields.

5.1.2 ILUC - Chain of Custody and Traceability

ISCC employs a mass balance chain-of-custody, which is also used for managing low ILUC-risk material flows. Under mass balance, certified sustainable biomass can be mixed with conventional material in the supply chain, but quantities are strictly accounted so that claims do not exceed actual certified volumes.

For low ILUC-risk, ISCC requires that the additional biomass volume be tracked as a distinct output from the farm through to the final product. Once a farm is certified for a specific amount of additional low ILUC biomass, this volume can carry a low ILUC risk claim on sustainability declarations. Downstream operators may forward the claim, but they must

ensure that the claimed volume does not exceed the amount received and that records are properly maintained.

The ISCC add-on guidance explicitly allows on-product claims of low ILUC risk only for operators handling such certified batches, and it requires the application of conversion factors to adjust the claimable volume for processing yields. For example, if 100 t of low-ILUC soybeans are processed into 20 t of biodiesel, only 20 t biodiesel can be marketed as low-ILUC. Regular ISCC audits verify the bookkeeping and traceability of these claims.

Segregation is not strictly required as low ILUC biomass can be co-processed with other certified biomass under mass balance. However, the accounting must prevent any dilution of the claim. ISCC also allows group certification for smallholders, where a group manager or first gathering point aggregates certified volumes and manages traceability collectively.

5.1.3 ILUC - Audit Process

All ISCC schemes require annual audits by independent certification bodies. For the low ILUC add-on, ISCC stipulates an initial audit to establish the project's baseline, including historical yield data, land status, and additionality measures. Regular audits, typically every 12 months and often aligned with harvest cycles, then verify ongoing compliance. Auditors check farm records, conduct field visits, and ensure the low ILUC risk volumes are correctly calculated and reported.

The audit methodology is essentially the same in ISCC EU and PLUS, with both following the checklist defined by ISCC 202-07. ISCC CORSIA auditors similarly use the ISCC CORSIA checklist and the additional guidance document. In all cases, non-conformities such as failure to achieve the claimed yield increase or violation of land criteria would result in no low-ILUC volume being certified for that period. Certification bodies also verify downstream traceability, usually through the normal ISCC chain of custody audit, to ensure that low ILUC material is properly accounted for throughout the supply chain.

ISCC also allows the low ILUC audit to be conducted separately from the regular sustainability audit if needed, for example after harvest when yield data are available. This flexibility helps accurately capture the additional biomass certified.

5.1.4 Feedstock

ISCC's low ILUC certification can apply to any crop-based feedstock where ILUC risk is a concern (e.g. corn, soy, palm, rapeseed, etc.). However, it is especially relevant for feedstocks that regulators classify as high ILUC risk. For instance, the EU RED has identified

palm oil as having high ILUC risk due to historical trends[1]. Biofuels from such feedstocks will be capped and phased out by 2030, unless they are certified as low ILUC-risk.

The ISCC 202-07 module provides a way to certify palm oil-based biofuel that was produced via yield increases or on additional land, so it can be counted despite the general cap. On the other hand, certain feedstock types are inherently low ILUC-risk and often treated favorably in policy positive lists. Wastes and residues (used cooking oil, agricultural residues, etc.) do not require ILUC add-ons and are typically assigned with zero ILUC by default. ISCC covers these feedstocks under separate waste and residue criteria.

Similarly, advanced non-food crops grown on marginal land, many listed in Annex IX of the EU RED, are considered low ILUC-risk in policy; ISCC certifies these under its regular scheme, but the low ILUC add-on can provide an extra claim of low ILUC-risk if needed for marketing or compliance. In summary, ISCC's framework recognizes that food/feed crops from existing cropland need special ILUC mitigation, whereas wastes, residues, and certain advanced feedstocks are intrinsically low risk and often explicitly exempt from ILUC-related limits in regulations.

5.1.5 ISCC EU vs ISCC CORSIA

ISCC CORSIA is a variant designed to meet the ICAO's CORSIA program for sustainable aviation fuels. Regarding ILUC, CORSIA uses the concept of low LUC risk for feedstocks that generate additional biomass. Under CORSIA, crop-based SAF typically carries a default ILUC emission factor, but this factor can be reduced to zero if approved low-ILUC-risk practices are applied.

ISCC CORSIA's low ILUC risk module is closely related to the ISCC EU 202-07 approach, including yield increase and unused land pathways[2]. There are differences in calculation methods, baseline periods and land eligibility definitions. ISCC CORSIA follows ICAO's methodology, while ISCC EU follows EU RED rules. ISCC CORSIA is recognized by ICAO for CORSIA compliance, whereas ISCC EU and ISCC PLUS are not automatically accepted under CORSIA. In practice, the modules share a common basis, and a producer meeting ISCC EU low ILUC requirements would generally meet the core CORSIA requirements, although a separate CORSIA certificate may still be needed.

[1] European Commision (2019). Report From the Commission to The European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the status of production expansion of relevant food and feed crops worldwide. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0142&from=DE, Assessed: Apr 2026

[2] ISCC (2022). ISCC CORSIA Guidance for Low LUC Risk Certification. Available: https://www.iscc-system.org/wp-content/uploads/2022/05/ISCC_CORSIA_Guidance_for_low_LUC_risk_certification_v1.1.pdf, Accessed: Apr 2026

5.2 Roundtable on Sustainable Biomaterials (RSB) and ILUC Risk

The RSB is another leading sustainability scheme which has proactively addressed ILUC. Its approach is set out in the "Low ILUC Risk Biomass" module, a voluntary add-on to RSB's main certification that operators can use to make additional claims about minimal ILUC risk[1]. Similar to ISCC, RSB's module is not a standalone certificate. An operator must first be RSB certified against its broader sustainability Principles and Criteria before applying the low ILUC risk module.

RSB recognizes three approved approaches to demonstrate low ILUC risk biomass. The first two are highly similar to ISCC: yield increase on existing agricultural land and cultivation on unused or degraded land. In both cases, the operator must prove that additional biomass is produced without displacing existing production, using baselines, land use evidence and additionality checks.

Another pathway explicit under RSB is the use of wastes and residues. This allows waste-based or residue-based biofuels to carry a low ILUC claim, provided the material is genuinely a residue, and its diversion does not create indirect effects. For example, if crop residues were previously used as animal bedding or soil input, the operator must show that sufficient excess supply exists or that the new use does not displace prior demand. This makes RSB's treatment of residues more detailed than schemes that simply treat residues as low ILUC by default.

5.3 Regulatory Frameworks: ILUC in EU RED, ICAO CORSIA, RenovaBio in Brazil and IMO requirements

Regulations have increasingly driven the need for ILUC risk considerations, and the certification schemes serve as implementation tools for these rules.

5.3.1 EU RED

The EU Renewable Energy Directive (RED II, updated by RED III) was the first legislation to directly address ILUC. It caps food- and feed-based biofuels that member states can count toward targets and requires high-ILUC-risk biofuels, such as those linked to expansion into high-carbon stock land, to be phased out by 2030. Crucially, EU RED introduced an exemption for certified low ILUC-risk biofuels, meaning that certified additional biomass can be excluded from the cap.

[1] RSB (2025). RSB Low ILUC Risk Biomass Module – RSB. Available: https://rsb.org/certification/certification-schemes/rsb-iluc-low-risk-biomass-module/, Accessed: Apr 2026

Delegated Regulation (EU) 2019/807 defines high ILUC risk feedstocks and sets criteria for low ILUC risk certification, including additionality, documentation and auditing [1]. Implementing Regulation 2022/996 provides further guidance for verifiers. These documents form the basis for ISCC and RSB low ILUC modules[2]. In practice, a biofuel counted as low ILUC risk in the EU must be certified by an EU approved voluntary scheme. The Union Database also supports traceability and helps prevent double claiming of certified volumes.

5.3.2 ICAO CORSIA

CORSIA established sustainability criteria for SAF that airlines use to meet their emissions-reduction goals. While CORSIA's core criteria initially focused on direct land use such as no conversion of sensitive areas after 2008, ICAO also recognized ILUC as a factor affecting true emissions. ICAO provides default ILUC values for different feedstock pathways, but producers can reduce the ILUC factor to zero if the feedstock meets approved low ILUC risk criteria[3].

The eligible practices are essentially the same two approaches: additional yield or use of unused land. ICAO does not directly certify producers. Instead, it relies on countries and approved certification schemes such as ISCC CORSIA and RSB. These schemes provide the low ILUC risk label needed for CORSIA compliance, and airlines can then report such SAF with a zero ILUC factor. Although CORSIA applies only to fuels claimed under the scheme, it has become a de facto industry standard for SAF credibility.

5.3.3 RenovaBio

Unlike ISCC and RSB, RenovaBio does not have a dedicated low-ILUC-risk certification module and does not provide a project-level low ILUC add-on claim. RenovaBio does not assign a separate numerical ILUC factor. Recent technical literature describes RenovaBio as treating land-use change through a risk-based approach, rather than assigning numerical ILUC emissions within the carbon intensity calculation[4] [5]. This reflects the broader difficulty

[1] European Union (2019). Commission delegated regulation (EU) 2019/807. Available: https://eur-lex.europa.eu/eli/reg_del/2019/807/oj/eng, Accessed: Apr 2026
[2] European Union (2022). Commission implementation regulation (EU) 2022/996. Available: https://eur-lex.europa.eu/eli/reg_impl/2022/996/oj/eng, Accessed: Apr 2026
[3] ICAO (2025). CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels. Available: https://www.icao.int/sites/default/files/environmental-protection/CORSIA/Documents/CORSIA%20Eligible%20Fuels/ICAO-document-06-Default-Life-Cycle-Emissions-November-2025.pdf, Accessed: Apr 2026
[4] Pereira et al. (2025). RenovaCalc: Calculation of carbon intensities under Brazil's National Biofuel Policy. Sustainability, 17, 10442. Available: https://doi.org/10.3390/su172310442, Accessed: Apr 2026
[5] IEA Bioenergy (2024). Evaluation of the Brazilian RenovaBio "conversion-free" criteria on land use change emissions related to biofuels. IEA Bioenergy Task 45. Available: https://www.ieabioenergy.com/wp-content/uploads/2024/11/Report_ILUC_RenovaBio_t45_Final-version.pdf, Accessed: Apr 2026

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of measuring ILUC, which depends on regional land markets, productivity, feedstock type and modelling assumptions.

5.3.4 IMO and Marine Fuels

IMO has been developing a lifecycle GHG assessment framework for marine fuels. In 2024, IMO adopted Guidelines on Life Cycle GHG Intensity of Marine Fuels, which acknowledged ILUC[1]. The guidelines define ILUC per ISO 14067 as land use change outside the product system, driven by market-mediated effects, and candidly discuss the difficulties of quantifying ILUC with certainty.

Due to the uncertainty, IMO currently does not assign default ILUC factors to marine fuels. Instead, it recommends a qualitative risk-based approach. Low ILUC risk projects are those that supply additional feedstock without disrupting existing land use, such as through yield increases, while high ILUC risk projects are those likely to displace food or feed crops onto new land. This language closely mirrors the EU and ICAO approach.

There is no official IMO certification scheme. However, ISCC and RSB already provide tools to implement these recommendations. In the EU, FuelEU Maritime links marine fuel sustainability to RED criteria, meaning that biofuels used for compliance must meet RED sustainability and GHG saving rules. Further, the FuelEU maritime excludes the usage of crop-based biofuels unless they're low-ILUC risk certified[2].

In summary, the maritime sector is now incorporating ILUC considerations. EU law ties marine fuel sustainability to RED ILUC criteria, while IMO guidelines acknowledge low ILUC risk feedstocks. Existing certification schemes can apply their ILUC modules to marine fuel supply chains as needed.

[1] IMO (2024). 2024 Guidelines on life cycle GHG intensity of marine fuels (MEPC.391(81)). Available: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.391(81).pdf, Accessed: Apr 2026

[2] EU (2023). REGULATION (EU) 2023/1805 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1805, Accessed: Jun 2026.

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6 CONCLUSION AND RECOMMENDATIONS

This report explored major aspects of several sustainability certification schemes, including GHG emissions quantification, traceability, and other sustainability themes. GHG emissions for all schemes were quantified across the well-to-wake life cycle of fuels, although ILUC quantification was not uniform across the schemes. Traceability generally required audits, with auditing required for the fuel producer/supplier across all schemes. Enhanced traceability measures in the form of radiocarbon tests were also observed in some schemes. Sustainability themes varied the most among the schemes, with some schemes having more themes and stricter rules, with some going beyond legislative requirements.

Stakeholder consultations were also conducted as part of the project to gain an idea of real-world considerations, implementation and challenges. Representatives from an ISCC-certified trader and producer as well as a Singapore-based Certification Body were interviewed. An expert in LCA from The International Council on Clean Transportation (ICCT) also provided valuable insight. The interview transcripts are attached in the Appendix. Selected findings from the interviews are listed here:

- Selection of the sustainability scheme is largely customer-driven.
- A mix of default and actual GHG emission values are used in practice, as using default values reduces the complexity of record-keeping, while actual values are usually lower.
- Training sessions by certification scheme operators are not conducted with sufficient frequency and the cost is inhibiting.
- Interpretation of the certification scheme system documents is sometimes subjective and auditors may interpret certain rules differently.
- Sustainability certification and audits are used to check for compliance. Due to the nature of audits on a sampling basis, it can discourage miscompliance and fraud, but it cannot completely eliminate the risk.
- Integrity-related issues were observed in certain markets, triggering the need for an expansion of integrity-auditing by scheme operators.
- The UDB serves as a huge mass balance system, rather than relying only on SDs, which can be subject to tampering. UDB will provide a platform for verification of SDs.
- Physical verification of fuel sources, such as radiocarbon measurement to determine biogenic content, can be useful as it serves as independent corroboration. However, additional costs may be a deterrent.
- Audits for different schemes, e.g. ISCC EU and ISCC CORSIA, may be combined to reduce costs and preparation work, since these schemes share many similarities.
- The auditor pool in Singapore is small. For example, biogas certification will be important in the near future, but it is difficult to find experienced auditors locally

because there are no biogas plants in Singapore. Although auditors can be trained overseas, this is costly and few companies are willing to invest before the need is clear.

- One risk factor for Singapore may be that the SEA market has a high volume of high-risk material such as UCO and POME (palm oil mill effluent). These materials may flow through Singapore.
- In Singapore and Asia, sustainability certification is regulatory-driven. ISCC EU may not be the best fit for non-EU markets, as it is primarily used to demonstrate compliance with RED II/III (EU's Renewable Energy Directive).
- There is a general consensus that the effects of ILUC are real. Both quantitative and risk-based approaches have been applied to address these effects under sustainability directives.
- When the effects of ILUC are quantified in terms of GHG emissions (gCO_2e/MJ fuel), different economic models, assumptions and parameter choices heavily influence the results. Model harmonization by considering multiple economic models and conducting a Monte Carlo uncertainty analysis can help in identifying the most impactful parameters and assumptions.
- Methane emissions, both upstream and from engines, may be underestimated in current lifecycle GHG calculations. Similarly, N_2O emissions from ammonia energy converters may require further study as well.
- Calculators and a database of region-specific emission factors could streamline the results of lifecycle GHG calculations.
- Default values for GHG emissions should be conservatively high, and these values should ideally be based on primary data from producers.
- Beyond GHG emissions, water use is another important factor in sustainability certification. However, water use is typically governed locally, and it is difficult to set mandatory sustainability criteria for it under the certification schemes.

Based on the findings in this report, some recommendations for the IMO's SFCS are provided. These recommendations are classified into three categories:

<u>Elements addressed in the IMO LCA guidelines or subsequent IMO discussions</u>

- Suggested chain of custody models are physical segregation and mass balance. Book and claim is not recommended due to the difficulty in regulation. However, it may be beneficial to trial book and claim on a small and controllable scale in a voluntary market to reduce emissions from transporting alternative fuels.
- Crop-based biofuels have implications beyond GHG emissions and ILUC, as excessive reliance may affect global food security. Some sustainability schemes impose a cap on crop-based biofuels and do not consider quantitative ILUC values

due to inherent uncertainty, while others use a mean ILUC value from two models when computing the GHG intensity of crop-based fuels. The GESAMP-LCA Working Group has recommended establishing high-, medium-, and low-ILUC risk classifications[1], with a tiered approach for the low-ILUC risk class, although the implications of each classification are not clear yet. To balance the near-term supply availability of sustainable marine fuels and the potential adverse effects of using crop-based biofuels, we recommend applying a hybrid risk-based and quantitative approach to ILUC. Quantitative ILUC values can be used to penalize the carbon intensity (and therefore the attractiveness) of crop-based biofuels while still allowing their usage. High-risk ILUC feedstocks can be subject to quantitative ILUC values and usage caps, or eventually phased out. Medium-risk ILUC feedstocks should be subject to quantitative ILUC values, while the low-ILUC risk certified feedstocks need not be subject to caps or quantitative ILUC values.

Elements pending or under discussion

- The emission factors for renewable energy are set at zero under selected sustainability schemes as infrastructure contributions to GHG emissions are not considered. This may not be reasonable, as different renewable energy sources have significantly different emission factors, such as solar (64 gCO_2e/kWh) and wind (31 gCO_2e/kWh)[2]. This difference in renewable energy emission factors should be reflected in the GHG fuel intensity of e-fuels as a significant portion of the lifecycle emissions of e-fuels stems from the embedded emissions from energy production. The difference will not be reflected if the emission factor for the renewable energy source is set as zero. However, averaging these values over the lifetime of the renewable energy source may hinder the attainment of the net-zero target in later years. A weightage-adjusted averaging scheme may be used, in which more emissions from infrastructure are attributed to energy produced in earlier years, so that the emission factor eventually reduces to zero toward the end of the infrastructure's lifetime.
- To avoid complicating certification, only GHG emissions should be quantified. Other environmental criteria should remain qualitative, as they should already be subject to monitoring by national laws.

Elements deemed to be useful based on the findings in this study

- Plausibility checks are an important tool for spotting irregularities and verifying compliance. A comprehensive database of relevant values should be compiled as a

[1] IMO MEPC (2025). MEPC 84/7/15 REDUCTION OF GHG EMISSIONS FROM SHIPS - Report of the second meeting of GESAMP-LCA Working Group. Available: https://docs.imo.org
[2] Zhang, X., Su, J., & Zhou, Y. (2025). Observing the impact of renewable electricity on the emission factors of electric vehicles using electricity generation data. *Scientific Reports*, *15*(1), 42418.

reference point for auditors. The database should include a common list of process inputs and the corresponding magnitudes for the production of sustainable fuels, as a GHG expert may not be familiar with all fuel pathways.

- A database of input-specific emission factors (for electricity, common chemicals etc.) should be built and updated regularly to ensure comparability of the calculated fuel carbon intensities.
- Physical measurements or fingerprinting of fuels may be useful for compliance verification and to deter fraudulent activities. It may be beneficial to the certification system when used in place of surveillance audits. However, further research is needed on the techno-economic feasibility, methodology for different fuels, implementation and limitations.
- To prevent double claiming, a central database where all transactions must be logged should be set up. The SFCS should also mandate that documentation held by the economic operator from other sustainability schemes must be made available for auditing.
- Certification scheme operators should increase the availability and accessibility of training sessions.

A few recommendations are also provided in the context of Singapore as a global maritime hub, based mainly on insights from the interview with the representative from the Certification Body:

- Singapore should consider facilitating the training of auditors for sustainability certification, e.g. by providing training subsidies.
- Additional measures such as fingerprinting may be useful, as many high-risk materials from Southeast Asia may flow through Singapore.
- In the selection of sustainability schemes for demonstration of regulatory compliance or for claiming carbon credits in a voluntary market, purely voluntary schemes such as the ISCC PLUS may be of more reference value to Singapore, as schemes like the ISCC EU are tailored for the EU market, and certain concepts may not be applicable to the Singaporean or Asian market.

7 APPENDIX

The appendix contains the interview transcripts from the stakeholder interviews conducted as part of the project.

7.1 Interview Transcript: ISCC-certified Trader and Producer

The following is the interview transcript (edited for clarity) with a representative from an organization that holds ISCC certification in Trader with Storage and Processing Unit. Their processing unit produces hydrotreated vegetable oil (HVO) and sustainable aviation fuels (SAF). The interview was conducted in person on the 29th of May, 2026.

1. **Is there any reason for selecting ISCC out of all the available schemes?**

   Our company holds certifications in ISCC EU, ISCC PLUS and ISCC CORSIA, as well as RSB. Our chosen certification is customer-driven as our end customers are mainly from Europe, where ISCC certification is widely utilised. The same certification is required throughout the supply chain to meet our contract requirements. Our feedstock suppliers must be ISCC EU certified. Although ISCC does recognise certain equivalent certifications, selecting the same certification along the entire supply chain reduces the uncertainty in compliance and in fulfilling our contract requirements.

   RSB certification may be preferred in other regions, but our products are mainly transacted under the ISCC schemes for the aforementioned reasons.

2. **What considerations do you have when you select your certification body? Is perceived credibility a key factor even if they are already recognised by ISCC?**

   We have a rigorous selection process for certification bodies (CB). We interview several CBs from the ISCC-recognized list and assess their expertise in GHG calculations and their understanding of the ISCC handbook. During our assessment, we'll also look out for discrepancies among the interpretations of rules by the CBs. Another consideration is whether the CBs respond proactively to questions, and the contract terms, including costs and whether they place a limit on the number of queries from us. We also look at whether the CBs have branches in Singapore and China, as we have a trading office in Singapore and production facilities in China. This is to facilitate communication. We actively avoid selecting CBs on the blacklist. Some other companies may select CBs based on the auditors' language proficiency, but this is not a concern for us. Our main consideration is the CB's familiarity with the rules and regulations.

3. **Do the rules on feedstock certification lead to any difficulty in sourcing raw materials and production planning? If yes, why?**

Certain feedstocks such as crude palm oil and soybean oil are banned in some EU countries and their usage is subject to caps in some. We only use waste-based feedstocks such as UCO (used cooking oil) to avoid any risks associated with crop-based feedstocks. Waste-based feedstocks are still widely available, although we sometimes face stiff competition in procurement.

4. **Do you take any additional measures to ensure that your feedstock is truly waste-based?** (*measures other than the certification and PoS, like conducting your own audits, or purchasing from a pool of trusted suppliers*)

   Our end users conduct additional audits as part of their buyer due diligence. There are some concerns on the commercial side as we do not want to share our feedstock suppliers. We also have our own team in China performing due diligence, such as for UCO collection. ISCC also conducts surveillance audits for high-risk supply chains. In some countries such as the Netherlands, double-counting audits are required. (*Double-counting refers to the regulatory mechanism where energy from waste-based biofuels can be counted as double the actual energy value in GHG reduction targets*)

5. **Why do you use the mass balance chain of custody instead of physical segregation/identity preservation?**

   We primarily use sustainable feedstocks to produce our biofuels, but we also use small amounts of fossil-based materials. The requirements for physical segregation are difficult to meet, especially since all elements of the supply chain need to be certified under the physical segregation chain of custody. Therefore, we use the mass balance chain of custody.

6. **Do you think a book and claim system (where credits from sustainable fuels usage can be traded inter-sector) would be helpful in promoting the use of sustainable fuels? If yes, why?**

   Yes, it'd be useful. Physical product transportation increases GHG emissions. If the fuel can be used in the same country of production, but credits claimed elsewhere, it'd reduce the emissions and help in promoting sustainable fuels usage. Some aviation companies have already tried a book and claim system; however it is subject to many constraints.

7. **How does your company maintain separate mass balance and traceability records for each storage location? How does it ensure that sustainability declarations match the actual physical receipt and dispatch site?** (*e.g. do you use an internal management system or do you use any commercial platform?*)

   We have two production plants and a Singaporean trading company with different storage locations. Our commercial terms are FOB (free on board) at China, meaning

we are not responsible for shipping to our end users in Europe. This makes the mass balance record-keeping easier.

We use Excel spreadsheets for the mass balance records. To further reduce the administrative burden, we frequently use the annual longest feedstock transportation distance in GHG calculations when issuing Sustainability Declarations. With this method, our products will have the same GHG emission value. A second option is to use the actual transportation distances for each feedstock supplier. However, this will result in different GHG emission values that need to be tracked across multiple batches, increasing the administrative burden.

Mass balance bookkeeping is simpler when default values for GHG emissions are used. We use both DDV (disaggregated default value) and TDV (total default value). When we use the DDV, we use the actual value for production, and the default value for transportation.

Bookkeeping may be complex if feedstock suppliers are a mix of ISCC-certified and other certifications, but our company avoids this by using only ISCC-certified suppliers.

8. **For the trader with storage scope, what are the main operational challenges?** *E.g. Batch tracking? inventory timing mismatch? bookkeeping?*

We have contracts with (shipping) terminal operators for the use of their storage tanks. Under the contract, exclusive tanks are designated for our use at the terminal and there are dedicated pipelines as well. The contractual relationship is audited as part of the trader with storage certification. The terminal operators don't need to be ISCC-certified, so selecting a reliable terminal operator is important to us.

We require regular reports from the terminal operators, as they have their own system to record incoming and outgoing fuel shipments, including weighbridges and the usage of flow meters. We check for discrepancies between the weighbridge figures from our production plant and those from the terminal. Unit conversions may also lead to discrepancies, and we need to clarify the figures with the terminal. One example is when reports are in volumetric units while our contracts may be in metric tons. We would then need to clarify the density used in the unit conversion

Another operational issue arises from fuel discharge from the tanks, as some fuel remains in the tanks and is not pumped out. Since the input exceeds the output, there will be a surplus in the mass balance bookkeeping that carries forward to the next mass balance period. We assign the highest GHG emission value to this surplus to reduce our losses.

9. **What specific part of the ISCC audit process consistently requires the most subjective interpretation or debate between you and your auditor?**

   The usage of green electricity in GHG emission calculations has been a subject of debate. Some auditors require green electricity from a smart grid network, while others accept a certificate that shows the purchase of green electricity in the absence of a smart grid. Aside from ISCC's rules, we sometimes also need to adhere to country-specific certification rules, such as those from Germany and the Netherlands, depending on our end user. These require additional audits.

10. **Are there any difficulties with using the Union Database? What happens if you need to correct errors in the PoS?**

    The UDB requirement has been delayed. However, we have included UDB requirements in our contracts in preparation for its launch.

    Under the ISCC Nabisy system, any corrections to the PoS (Proof of Sustainability) need to be processed by the German government. They'll cancel the existing PoS, then reissue the corrected one.

11. **In practice, do you use more default values or actual values for carbon calculations? Why?**

    We use both default and actual values. TDVs require less auditing. Using DDVs with the actual value for emissions from production results in a lower GHG emissions value. If more emission reductions are required, using the actual value is better.

    (*also refer to the answer to question 7*)

12. **Do you think using actual values improves the accuracy of the results? And why?**

    Technically, the actual values should better reflect the lifecycle GHG emissions. However, in practice, default values facilitate mass balance bookkeeping.

    (*also refer to the answer to question 11*)

13. **Would it be helpful to have a calculator tool to help with the GHG emissions calculation? (show a sample from CARB LCFS)**

    It would be helpful. For producers and traders who want to enter the IMO sustainable marine fuels market, it's helpful for those who don't hire consultants, as it gives them an idea of their fuel products' GHG values.

    It is also useful for auditors to gain a better understanding of the production process and life-cycle inventory, although they will also review process flow diagrams prior to on-site audits.

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For those who want to achieve better actual values, they may use actual emission factors instead of the default ones provided in the calculator and actual consumption values.

14. In your experience, what is the biggest challenge in GHG emission accounting during the certification process?

It is difficult to meet the requirement to use green electricity emission factors in calculating the actual value. (*refer to the answer to question 9*)

Another difficulty stems from the auditor's acknowledgment of the entire production process. Our process is complex, including several reactors and wastewater treatment systems. It is much more complex than FAME (fatty acid methyl esters) production.

We have to work closely with the GHG auditors to avoid double-counting of emissions. For example, they may count the emissions from DI water (deionised water) and steam. However, DI water is used to produce steam, so they should not sum the emissions from both (because the emissions for steam already include those from DI water). Some confusion also arises in quantifying the emissions in wastewater recycling, as water is reused. Another challenge lies with quantifying GHG emissions from catalyst use, as we do not want to reveal our proprietary information. To overcome this, the major chemicals are accounted for in GHG calculations.

Following the audit, the ISCC auditor will submit a report and no further action is required if the report is accepted. However, sometimes follow-ups are needed.

15. How does your company demonstrate compliance with ISCC environmental, social and economic requirements across collection, storage, trading and processing activities?

a. **Environmental requirements (ISCC Principles 2-6 cover environmental protection, including soil, water, air, waste and GHG-related practices): prevention of leakage, contamination, wastewater management, energy use?**
b. **Social requirements (e.g. including safe working conditions, training, labour rights, and responsible community relations under ISCC Principles 3 and 4): workers involved in collection, storage, transport and processing operations?**
c. **Economic and governance dimensions (ISCC Principle 5 covers legal compliance and anti-corruption, Principle 6 covers good management practices and continuous improvement): legal compliance, anti-bribery,**

conflict-of-interest controls, supplier due diligence and continuous improvement of management systems?

We demonstrate compliance through a KYC, Know Your Company, process when we vet our suppliers and customers. We also look at ESG (environmental, social, governance) reports. Our suppliers and end-users need to complete a questionnaire, including a question about whether they're on the sanctions list.

Our production company issues ESG reports. Our ISCC management system documentation covers these compliance aspects.

16. **From an industry perspective, what do you think is the biggest gap or weakness in the current sustainable fuel certification system? And what would you improve?**

    Each CB seems to have their own understanding of the standard. There appears to be a lack of training from ISCC, and those available are costly. They should launch more training sessions and workshops. To improve, they should provide more training and reduce the cost. There should also be more interaction between ISCC and the industry, such as with the producers.

17. **Is it feasible to combine audits from different schemes e.g. ISCC EU and ISCC CORSIA for cost reduction?**

    In practice, this is difficult as our certificates have different expiry dates.

18. **Any general comments about sustainable fuels certification?**

    None for now.

7.2 Interview Transcript: Certification Body

The following transcript (edited for clarity) documents the interview with Jomaine Tang of Double Helix Tracking Technologies, an ISCC Certification Body based in Singapore. The interview was conducted on the 4th of June, 2026 via a Teams online meeting.

1. **Could you briefly describe your experience as an auditor?**

   I'm the Certification Manager at DoubleHelix, so I don't partake in audits that much, although I'm familiar with the procedures, rules and regulations. For some of the more operational questions, I have consulted our ISCC auditor with roughly 3.5 years of experience. My answers will mostly be based on the ISCC EU scheme. We are also recognised as a CB (Certification Body) for ISCC PLUS and CORSIA, and work with some other schemes.
   Our company entered the Singapore market in 2023, primarily due to interest from the EU and the UK, leading to a growing market. In the beginning, not many

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industry players in Singapore knew about ISCC, and we had to explain a lot about ISCC. The industry is generally more aware of ISCC now, they know about the sustainability certification concept for the supply chain.
Double Helix is a Singapore-registered company with a UK partner that also delivers the service to EU. The SG side is in charge of the SEA market.
Most companies in SG apply for certification to meet compliance requirements, whether it is regulatory or client-driven. Recently, there is more forward-looking demand, without any specific compliance requirement.
We mostly certify traders based in Singapore, though recently there has been an increase in (certification work for) processing units and collection points.

Waste/residue verification

2. **For used cooking oil and other high-risk waste/residue feedstocks, do you think measures like surveillance audits are sufficient to deter mislabelling? Why and do you think any other measures can be taken?**

The nature of certification systems is such that audits are on a sampling basis. If an entity is bent on committing fraud, they'll find a way to do so.
The market can take extra measures, but a balance is needed between additional prevention efforts and cost-effectiveness.
Audits will not be 100% fool-proof. The additional surveillance audit (for high-risk supply chains such as certain waste/residue) is only compulsory in the 1st year and not during re-certification. The intention may be to check for mistakes and educate the EO (economic operator) when they are still new, rather than to capture fraud.
Some measures may help, such as blockchain (to prevent unauthorized alteration). The UDB by the European Commission also helps. It is an online platform where all EOs need to record all trades linked to the ISCC EU for the European market (in the future). The UDB serves as a huge mass balance system, rather than relying only on SDs, which can be subject to tampering. UDB will provide a platform for verification (of SDs).
Mislabelling may occur due to a lack of knowledge. For example, UCO is a waste material, while expired cooking oil is not technically a waste material, but suppliers may declare it (expired cooking oil) as UCO since it is no longer usable.

Farms and plantations are agricultural operations where the agricultural material is produced. Points of Origins are the operations where the waste or residues are first generated. These two types of scopes can be certified under first gathering point scopes or collecting point scopes where sample audits are selected and conducted on a risk basis.

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ISCC has a requirement on the number of sample audits for non-certified entities (for example, square root rule). These are typically on-site audits. They have to prepare all documents, and auditors will randomly select documents for checking, based on volume and risk.

Low ILUC-risk

3. **For low ILUC (induced/indirect land use change) risk certification, how do auditors assess and verify in practice whether additional biomass is truly additional beyond business-as-usual practices, for example through yield increase, unused land, or improved agricultural practices?**

We don't have much experience with this in the Asian market, as the materials here are usually waste or residues.
These (aspects for low ILUC certification) must be verified on-site with observation of the actual business practice, such as whether there was an equipment update. The auditor must have industry knowledge on whether the measures are beyond the norm, and they also interview workers on-site. The entity must prove that they need the ILUC risk certification and the burden of proof lies on them.

Additional response from a UK-based ISCC auditor:
Low-ILUC Risk: From my experience auditing a large number of biomethane and bioenergy supply chains, the main focus is demonstrating additionality. I look for clear evidence that biomass production has increased through measures such as yield improvements, better agricultural practices, double cropping, or the use of previously unused/degraded land. This is typically supported by historical yield data, farm records, and documentation showing a direct link between the implemented measure and the additional biomass produced. A lot of the audits I have done are in the UK and Europe however where this (low-ILUC risk certification) is less applicable.

Environmental, social and economic requirements

4. **Beyond GHG emission savings, what environmental criteria are most difficult to verify during audits, such as biodiversity protection, high carbon stock land, peatland, water use, or soil protection? Are satellite images always available to ensure no deforestation has occurred?**

   There is an ARIA (automatic risk assessment) tool under ISCC to help with this. We generally just follow practices recommended in ISCC EU 202-04. We check EIA (environmental impact assessment) reports, forest/land management plans and so on.
   Asian system users mainly trade waste-based materials; there isn't much demand for farmland and forestry certification.

5. **How are social and labour requirements verified in practice, particularly for small suppliers, collectors, or upstream feedstock producers in countries with different labour standards?**

   We would check waste management systems, health and safety policy and training records. We also conduct on-site observations, interviews with the workers and inspect the implementation of safety management systems such as hazard signs.
   Since ISCC EU uses a chain of custody certification model, all upstream entities (relative to traders in SG), even if they are located in different countries, need to be certified as they are economic operators.
   Each entity (along the supply chain) ensures that they meet their own certification requirements; there is no additional burden on downstream system users to verify compliance by their upstream entities. This is one of the features of a chain of custody certification model.

6. **Some certification schemes require calls for public comments before an economic operator achieves certification. What do you think about this?**

   ISCC has a platform for whistleblowing, but it's not required for each individual certification.

Chain of Custody

7. **Have you or your colleagues encountered any difficulties in verifying mass balance records? How did you handle them? (*some discrepancies are unavoidable due to transportation losses, or measurement uncertainty*)**

There is an acceptable tolerance level of 0.5% allowed under ISCC due to transfer loss. When there is a deviation (beyond 0.5%), auditors will check whether the discrepancy was plausible, and whether it was accurately recorded and accounted for in the mass balance records. Losses must be accounted for.
One real-life case is when a barge transports a small amount of material, the percentage deviation may then be large. System users can back it up with their records and reasonable explanations.
Any loss should be captured in the mass balance to ensure that material physically lost cannot be sold.

8. **In practice, how does the co-processing certification work? How does the producer prove that the sample taken for radiocarbon sampling is representative? (e.g. does the auditor witness the discharge of the product to a tank before the sample is taken?)**

   I can help forward this question to our UK counterparts, who are more familiar with the certification of processing units.

   Response from a UK-based ISCC auditor:
   Chain of Custody (Co-processing): While most of my experience is in biomethane rather than co-processing facilities, the key principle is demonstrating that the sample is representative of the certified product stream. During audits, I verify the sampling procedure, traceability records, tank inventories, production records, and laboratory documentation. Where required, sampling may be witnessed, but often the emphasis is on having a robust, documented process that demonstrates the integrity and representativeness of the sample. Essentially, a lot of trial data and historic data is required to demonstrate how the co-processing splits are determined. It can't be speculative. I have not seen many adopt radiocarbon methods though.

9. **How is the method for co-processing conversion factor calculation selected? Can the economic operator select any method that they want among energetic, mass, yield and C-14? Which method is the most common?**

   (refer to the answer to question 8)

10. **In your opinion/experience, does the book and claim system create any practical verification challenges or fraud risks that a physical chain of custody would avoid? What safeguards do you think are most important?**

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We don't have any experience with book and claim systems. Since there's no physical link, there may be more difficulties in ensuring that double-claiming doesn't happen.

Audit

11. How long does the audit process take for a trader/processing unit?

This depends on the scope. For Points of Origins and traders, it may take one day or less for the on-site audit.
For processing units, more effort is needed. Auditors need to understand the material conversion process and losses. The time required will also depend on the number of materials (raw material and product types), process complexity and number of storage sites.
Pre-auditing is encouraged. The applicant sends their management system documents, mass balance templates and sometimes their (mass balance) records as well. Any soft copies of ISCC documents can be pre-audited to minimise on-site checks for documentation. In this way, our auditors can spend more time on interviews and activities that must be done on-site.

As a side note related to on-site audits, we can use external auditors not directly employed by our company. We have to ensure that the auditors adhere to our procedures and practices as a certification body. The final certification decision still lies with us, but we will consider the auditors' report and findings in making the decision. ISCC paused sub-contracting in late 2025 to put in additional requirements. These have been released lately and are largely to prevent conflicts of interest and put in place better monitoring mechanisms of the subcontractors. It was shared with us that the trigger for this development was due to the rise in ISCC integrity-related issues in China. In addition, we were informed that ISCC is expanding its integrity team.

12. When reviewing data submissions, what are the most common inconsistencies or red flags you look for? Are there particular operator types where data quality tends to be weaker?

We look at things like consistencies of sales volumes and dates, knowledge and attitude of implementors in the company and how familiar they are with the process.

For smaller stakeholders, record keeping may not be a priority. An example is from points of origins selling to collecting points collecting UCO (used cooking oil). (collecting points receive sustainable materials from small family-owned restaurants) Restaurants may not weigh the UCO as the effort does not benefit them much. Some improve their practices after CBs provide good practice recommendations from on-site audits.
Another recommendation from us is that collecting point operators may help their points of origins fill out the Self-Declaration, and the point of origin operators can countersign after confirming the information.
It may not be realistic to expect records from small family restaurants to be complete, when comparing them to international or chain restaurants.
From our experience, data quality is more related to geographic distribution, risk level of materials and level of knowledge within a company, instead of being linked to operator type or scope.

13. **Do you think a database of common values would be useful to guide plausibility checks, and why?**

Yes, it would be useful as a yardstick. It can be useful when coupled with observations on-site, and supplemented by experience.

14. **Do you think digital technologies such as blockchain, digital MRV systems, or AI-assisted monitoring could improve certification robustness? Are these technologies on the way?**

Yes, it could be helpful, but it requires regulation for market adoption. The ISCC EU uptake relied on regulation, not voluntary markets. Implementation may also be challenging, as shown by the continued postponement of the UDB (Union Database) requirement.

15. **Do you think physical verification (using tests like C-14 tests) is a good complement to audits for demonstrating compliance? Why?**

In theory, it sounds good as it may serve as independent corroboration, but additional cost is always a deterrent. From our experience in the timber sector, isotope testing, DNA testing, species testing can be used to determine whether timber is from a specific geographic region or of a certain species, to check whether it matches the declaration. Verification modes are market-driven. Clients prefer

relying on documentation as this is the cheapest and easiest method. Testing always means additional costs, and takes time for results.
It (fingerprinting) may be used in isolated cases, such as when a timber shipment has been flagged by the authorities, and tests may be used to prove credibility.

16. **To avoid double claiming, we understand that auditors have access to records from other sustainability certifications held by the operator. Do you think this measure is sufficient? Have you encountered any suspected cases?**

We check records on a sampling basis as it is not feasible to check all transactions. This is mostly to ensure that there are no red flags. We haven't seen any cases in Singapore.

17. **Would it be practical to combine audits for two different schemes such as ISCC EU and ISCC CORSIA? What are the pros and cons?**

Yes, we encourage clients to do them (audits) at the same time. ISCC has an electronic (audit) checklist which can be filtered to display questions relevant to each scheme selected. Choosing ISCC EU will unlock specific questions and choosing ISCC CORSIA will unlock a certain set of questions.
Since there are many similarities, some preparation work such as management documents may be shared across schemes.
APS (audit procedure system) helps streamline process to ensure auditors check everything that should be checked (audit checklist with built-in logic).
Combining certification audits can cut audit time and preparation work.
Clients must understand what the differences are.
If the certifications are 6 months apart (after 2 initial, separate certifications), we can try to sync ISCC EU and ISCC CORSIA certifications by invalidating one (the one not due for renewal) during the renewal audit, and issuing both certifications at the same time (after auditing both schemes both). This will lead to long-term cost savings for clients.

18. **What is the most commonly identified non-conformity, and what are the corrective actions usually required?**

For traders in Singapore, human errors are the most common, such as typos. These will be corrected based on the (other) records, and it is not a serious non-conformity if the claims are not passed along.

An uncommon non-conformity is issuing a wrong Sustainability Declaration (SD). When this happens, the system user must write to the entity who received the wrong SD, as well as that entity's CB. The error must be rectified in the mass balance records. We have experienced receiving a wrong SD. ISCC has set out a standard course of action for when wrong SDs have been issued and how all parties should manage the situation.

GHG emissions accounting

19. **In your experience, what is the biggest challenge in GHG emission accounting during the certification process?**

As we deal mostly with traders, we don't have much experience with actual GHG calculations beyond ensuring correct transportation distances. We can help check with our European counterparts.

Response from a UK-based ISCC auditor:
GHG Emissions: The biggest challenge I encounter during audits is the quality and completeness of source data. GHG calculations are often straightforward in principle, but obtaining accurate input data from all parts of the supply chain can be difficult. In biomethane projects specifically, feedstock data, transport distances, energy consumption, and methane leakage assumptions are often the areas that require the most scrutiny.

20. **Have you encountered any difficulties sourcing emission factors (aside from the ones provided by EU RED)? Do you think a more comprehensive, up-to-date database would be useful for GHG calculations?**

More comprehensive databases are always better. Sometimes EFs (emission factors) may need to come from overseas.
Some (EFs in Singapore) are available from EMA (Energy Market Authority) for electricity and water.
Audits of calculations should adhere to ISO 17029 (Conformity assessment). A very common issue is to justify which EF to use.

21. **Would a customizable calculator tool (with pre-defined inventory items for selected fuel pathways) be helpful in computing GHG emissions, and why or why not?**

It's OK if it's flexible enough. For ISCC/ISO, auditors need to check the methodology, so calculation formulae must be known. It (the results from the calculator tool) needs to be verifiable.

22. **How clearly defined do you find the certification rules around carbon sources for RFNBO and RCFs and renewable electricity? Have you encountered situations where the rules were interpreted differently across certification bodies, or were difficult to apply in non-EU contexts?**

We're not familiar with these as these are mostly applicable to processing units. We can help check with our EU counterparts.
In some other cases, Double Helix has sought clarification from scheme operators, but the responses were not very helpful. This appears to be a general regulation issue, not a scheme operator issue, as scheme operators only help implement the rules. We believe the wordings (from scheme operators) are intentionally kept vague to allow for maneuvering.
CBs prefer to seek clarification from scheme operators. If the answer is not forthcoming, CBs will try their best to decide based on past experience and other methods, like past cases.

Response from a UK-based ISCC auditor:
RFNBO / RCF Carbon Sources & Renewable Electricity: As mentioned, my experience has primarily been within biomethane certification, but from what I have seen, the rules around carbon sources and renewable electricity have become much more detailed over the last few years. The main challenges tend to be demonstrating compliance with renewable electricity requirements and maintaining sufficient evidence throughout the chain of custody.

General

23. **What specific part of the ISCC audit process consistently requires the most subjective interpretation or debate between you and the economic operator?**

Here in Singapore, the system users reach out to us to clarify issues, so there is not much debate. There are more issues with seeking clarification from scheme operators, as shared earlier.

24. **From your experience, what are the most challenging parts of certifying sustainable fuels in practice, other than those mentioned above?**

We received some feedback from a client that default values lead to underestimation of GHG savings and the differences can be large. However, using actual values leads to more administrative and operational burdens.

25. If you could change one or two things about how sustainable fuels certification schemes are designed or implemented, what would they be?

Scheme operators should make training more readily available and frequent.
There is a lot of useful information in the system updates, but it is difficult to search for these systematically. Sometimes we try to find a use case (among the system updates), but it is hard to find the relevant ones.
The information is scattered and not necessarily in one document.

26. Is the current pool of qualified auditors keeping pace with the growing demand from new sustainability directives? What barriers, if any, do you see to expanding auditor capacity?

From a Singapore perspective, biogas and biomethane certification will be important soon. However, it is hard to find experienced auditors locally since there is no biogas plant in Singapore. We may collaborate with our European counterparts to train auditors, but we'll have to train auditors almost from scratch, and the manpower pool of people with the relevant work experience in Singapore is small. This is also costly and the cost may not be justifiable before the demand is clear.
For some scopes like farm and plantations, auditors need specific backgrounds related to agricultural farming, geology, and forestry experience. It's hard to find candidates who can meet these requirements in Singapore.
Auditors need to meet minimum requirements from ISCC, like having a certain (knowledge) background, and a certain number of audit days. The auditors also need a certain level of confidence to conduct audits independently (even if they have been trained).

27. Do you have any general comments about sustainable fuels certification, especially in regard to Singapore or Southeast Asia?

In Singapore and Asia, sustainability certification is very regulatory driven. ISCC EU may not be the best fit for non-EU markets, as it is primarily used to demonstrate compliance with RED II/III (EU's Renewable Energy Directive). The EC (European Commission) may make changes that are more relevant to the EU market. If

Singapore uses the ISCC EU standard, it may not reflect the actual regulatory requirement for Singapore.

For example, the EC (in future) requires all ISCC EU EOs to use the UDB for reporting. But for EOs outside of the EU, the gas grid is not linked to the UDB if they're using a gas grid outside of the EU, and this cannot be reported on the UDB platform.

We have sought clarification from ISCC previously. ISCC EU is EU-oriented, and they must adhere to the relevant changes. It is unlikely that they'll take on considerations from other markets. ISCC recommended using ISCC PLUS. It is a voluntary scheme and therefore not subject to changes in the EU RED.

One risk factor for Singapore may be that the SEA market has a high volume of high-risk material such as UCO and POME (palm oil mill effluent). These may flow through Singapore.

7.3 Questionnaire response: NGO

The questionnaire response (received on the 15th of July, 2026) from Dr. Gonca Seber, Senior Researcher at the The International Council on Clean Transportation (ICCT) is attached below. ICCT is a nonprofit research organization that provides environmental research on transport to environmental regulators.

1. **In your view, are current sustainability directives and certification frameworks adequately addressing ILUC? If not, what are the most critical gaps, and which policy approach would you recommend?**

   It depends heavily on the jurisdiction and framework in question. While there is a general consensus that these effects are real, there is less consensus on how to address them. It is possible to quantify ILUC emission factors and then use them in the well-to-wake emission factors, as in the California LCFS, ICAO CORSIA, or EPA's RFS. Although there is uncertainty in model estimates due to the model used and the assumptions made, this uncertainty can be reduced by using a multi-model approach, as in CORSIA.

   It could be simpler to adopt a risk-based approach, where fuels are eligible, ineligible, or capped based on their perceived risk. However, determining that risk can be challenging in its own right and can be done via ILUC modeling, quantitative analysis of deforestation (as in the EU), and a "positive list" of low-risk pathways such as wastes and residues. EU RED's risk-based approach is one of the more robust certification schemes when qualitative ILUC frameworks are considered.

2. **ILUC emission estimates vary considerably across models and underlying assumptions. How should policymakers handle this uncertainty when assessing**

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biofuel sustainability — for instance, through conservative defaults, scenario ranges, or model harmonization?

Each model has its own idiosyncrasies and shortfalls—no model is perfect. Model harmonization is one way to reduce uncertainty in economic models. For example, in ICAO's CORSIA, two different economic models with different assumptions are used, and, in the end, the midpoint value from these estimates is used when the difference between the estimates is within 10 percent of the baseline fossil fuel value of 89 gCO2e/MJ. That is, if the difference between the two model values for a particular region and pathway is 8.9 gCO2e/MJ or less, then the proposed ILUC value is the average of the two model results.

However, the differences between models may pale in comparison to the variation within a given model based on parameter choices and assumptions. Reviewing and ground-truthing these is critical to inform the credibility of any ILUC assessment. A Monte Carlo assessment can inform policymakers of the most impactful parameters, assumptions, and methodological choices. As ILUC effects could have severe consequences, it might make sense to take the conservative values from the estimations.

3. **How credible is low ILUC risk certification as a tool for reducing land-use impacts? Are there methodological weaknesses that undermine its reliability, and if so, how should they be addressed?**

   Low-ILUC risk certification provides exceptions for high-ILUC risk feedstocks/fuels; however, the key factor is that the practice mitigates market-mediated ILUC risk rather than simply demonstrating compliance within one given biofuel's supply chain. Therefore, the certification criteria should be robust and difficult to meet, making it hard to obtain a low-ILUC certification. For example, the EU's RED has strict measures to ensure biofuels feedstocks are sourced in addition to business-as-usual practices. Only additional biomass that has been produced after the low ILUC risk certification shall be eligible. For that, the RED criteria require a financial-attractiveness test, allow the cultivation of crops on abandoned or severely degraded land, etc. EU RED is the most robust low-ILUC certification scheme (when compared with CORSIA's land management practices or RSB's low-ILUC certification).

4. **Which emission sources or GHG species do you consider underestimated or insufficiently covered in current certification frameworks and/or the IMO LCA guidelines? (This might include fugitive emissions, non-CO_2, N_2O, CH_4 species or others.)**

   Upstream methane emissions (leaks) from natural gas supply chain are one of the factors that is often not considered or included in the LCA guidelines or databases. Fugitive methane emissions from ships are another topic that is underestimated within

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the current LCA guidelines of the IMO. In ICCT's first FUMES study (Fugitive and unburned methane emissions from ships) we found that ships using the most common LNG engine emitted 6.4% methane slip on average, compared to IMO's assumption of 3.5% and the EU's assumption of 3.1%.

N_2O emissions rates for ships that will use ammonia as a marine fuel are still unknown and, because of its high GWP, could play an important role in determining the ability of ammonia to reduce life-cycle GHG emissions. One way to understand N_2O emissions could be to require in-stack continuous emissions monitoring systems to monitor, report, and verify N_2O emissions for calculating the life-cycle GHG intensity of ammonia for regulatory compliance.

IMO has chosen not to include ILUC emission factors quantitatively in the LCA guidelines. ILUC emissions are one of the most important factors when evaluating the environmental performance of biofuels.

5. **Tools such as the Low Carbon Fuel Standard's pathway-specific calculators guide GHG accounting. Should such calculators be adopted or referenced in certification frameworks for sustainable fuels? What are the main advantages and risks of this approach?**

   Yes. These calculators are useful to streamline results through the use of similar emission factors for energy and material inputs within the biofuel's production pathway. These calculators should have region specific emission factors as necessary. For example, electricity emission factors change depending on the region and the electricity mix.

6. **Should certification frameworks be supported by a regularly updated, authority-maintained database of input-specific emission factors? What governance and update mechanisms would be necessary to make such a database reliable and credible?**

   Yes, governments could provide databases that are updated on regular basis, this will be useful to understand regional differences in input emission factors.

7. **Default values for GHG emissions, whether total or disaggregated, are important for plausibility checks and streamlining audits. What should be the approach to determining default values?**

   Conservatively high values are important. Basing these values on real-world, primary data is ideal. The methodology and data sources used to establish the default values should be transparent and well-documented. Such a practice could also motivate biofuels producers to eventually submit their own real-world values. If the default values

are too low, it will motivate only the best producers to submit data while risking the above average producers to stick with the default values.

8. **Beyond deforestation, should certification schemes enforce binding requirements on other sustainability dimensions — such as air quality, water use, and biodiversity? Currently, many schemes reference these themes but apply relatively weak rules. In your view, where should the boundary of mandatory certification criteria be drawn?**

   Water use is one of the most important factors that should be strictly considered. However, the difficulty in setting mandatory sustainability criteria is that each country has its own rules for water governance.

9. **Are there aspects of sustainable fuels certification — or gaps in current research — that you would particularly like to see addressed in our review?**

   Information on chain of custody methods, comparisons, and which is the ideal for international fuel certification frameworks such as ICAO or IMO.