Carbon Direct

2026 EDITION

Criteria for High-Quality Low Carbon Fuels

Contents

Introduction

The low carbon fuel (LCF) market is expanding rapidly, yet standards, definitions, and claims associated with LCF production and procurement vary widely across regions, certification schemes, and regulatory systems. This *2026 Criteria for High-Quality Low Carbon Fuels* builds upon existing frameworks from standard-setting bodies, regulatory agencies, buyer alliances, and academic research. Our goal is to consolidate key sustainability considerations and provide a unified set of high-quality criteria that is useful for decision-makers. **The intent of this guide is to help fuel buyers procure LCF from the voluntary market,** focusing on production pathways that are impactful, additional, and equitable.

Defining low carbon fuels

For the purposes of this document, an LCF is defined as an energy carrier whose life cycle greenhouse gas (GHG) emissions are lower than those of a relevant and use-case-specific fossil fuel baseline.[1] While LCFs may be produced through biogenic, synthetic, or other non-fossil pathways and used across multiple sectors, **this document focuses on biofuels for the transportation sector,** as these comprise the majority of current LCF production and use.[2] The initial focus on biofuels is not intended to signal a preference for biofuel pathways over synthetic or other LCF production methods. Future editions of this document will expand to cover additional pathways and feedstock categories. In this document, the term "LCF" refers to the physical biofuel and its associated environmental attributes.

This edition does not cover all biofuel feedstock categories or biofuel types. Manure-based feedstocks and municipal solid waste-derived feedstocks are excluded from this edition. Renewable natural gas (RNG) is also excluded, as RNG is commonly made from manure-based feedstocks through anaerobic digestion. Further detail on feedstock scope is provided in the *Feedstock sourcing* criteria section.

1 Please refer to the *Carbon accounting* criteria for further details on how GHG reductions are calculated for LCFs.

2 International Energy Agency. 2022. Total Biofuel Production by Feedstock, Main Case, 2021-2027. [accessed 2026 Jan 13]. https://www.iea.org/data-and-statistics/charts/total-biofuel-production-by-feedstock-main-case-2021-2027.

Essential principles for high-quality LCF production and use

The following principles characterize high-quality LCFs and the value chains through which they are produced, certified, and procured. These principles describe key considerations across all LCF pathways, within the scope of this edition as described above. Within each principle, individual criteria distinguish between requirements that *must* be met and considerations that *should* be addressed, where "must" denotes minimum thresholds for quality and integrity, and "should" reflects best practices or aspirational characteristics. These criteria are intended to serve as high-level guidelines that outline what must or should be demonstrated, without prescribing the specific methods or procedures through which compliance should be achieved. **The criteria place the responsibility for demonstrating compliance to a voluntary buyer on the fuel producer as the central actor within the LCF value chain.**

In addition to fuel producers and their upstream supply chains, these criteria also apply broadly to the procurement structures and market actors that collectively determine the sustainability outcomes of LCF use. Therefore, these criteria apply not only to individual projects and facilities, but to fuel blenders, coordinators and aggregators, and certificate traders. For this reason, **we use the term "LCF systems" to encompass the full set of production, certification, and procurement arrangements through which LCFs are generated and claimed.** Because these systems vary widely in structure, **credible assessment of LCF quality requires evaluation across the full supply chain:** from the point where feedstocks are generated ("point source"), through the fuel production process, and onward to distribution and end use.

The interplay between LCF sustainability certifications and these criteria

Several organizations, such as the Roundtable on Sustainable Biomaterials (RSB) and the International Sustainability and Carbon Certification (ISCC), have developed and publicly published standards for LCFs allowing market participants to certify their fuels against a defined set of sustainability criteria. These certifications typically assess the fuel's supply chain, from feedstock source to end use. Certification provides a level of assurance that the sustainability requirements established by these organizations are met.

Carbon Direct's *Criteria for High-Quality Low Carbon Fuels* serve as a comprehensive set of sustainability principles that buyers on the voluntary market can use to independently assess the sustainability of their LCF procurement. The criteria are not designed to complement or replace existing sustainability certification schemes such as RSB and ISCC. However, certain criteria included in this guide may already be addressed by a fuel's existing certification. Where this is the case, fuel producers should disclose relevant certification coverage to a buyer. Since certifications vary in scope and rigor, buyers should evaluate what criteria a given certification covers, identify where the certification aligns with these criteria, and determine where gaps may exist that require additional assessment or disclosure.

The dynamic nature of the LCF market

The market for LCFs, including biofuels, is evolving and continues to mature. As policy, certification systems, and supply chains emerge and develop, buyers on the voluntary market and other fuels market participants will need to apply these criteria with appropriate flexibility.

Adherence to the criteria in this document is important to maintain the credibility of LCF procurements. However, alignment with the criteria may not look the same for every system, particularly where data availability, traceability, or market structures limit what can be demonstrated. These criteria are meant to function as strong guardrails for LCF procurements, helping buyers set clear expectations and prioritize continuous improvement. Carbon Direct acknowledges that early-stage systems may not yet have the resources to demonstrate full adherence to all criteria, but should nonetheless commit the necessary resources to achieve compliance as the system matures. Further, buyers should use these criteria to inform their procurement decisions based on their own risk tolerances.

The 2026 edition

The *2026 Criteria for High-Quality Low Carbon Fuels* is an initial set of criteria for LCFs. This document is designed to be a living resource that will be updated on an annual basis to reflect market developments, emerging best practices, and stakeholder feedback. Future updates may include coverage of synthetic LCF pathways, RNG, sector-specific criteria (e.g., maritime fuels), and additional principles beyond the six described here.

Low carbon fuel principles

Social harms, benefits, and environmental justice

High-quality LCF systems do not exacerbate existing or create new social harms to people and communities; where existing social harms are identified, high-quality LCF systems work to mitigate them. Because concerns vary by LCF system, the harms that follow are not exhaustive, but describe some of the common and potentially negative impacts across LCF pathways. Beyond not exacerbating existing or creating new harms, high-quality LCF systems can provide additional social benefits to local communities, such as infrastructure improvement, job creation, and investment in climate resilience. The localized social harms, benefits, and potentially disproportionate health impacts of each major activity within the LCF system must be carefully reviewed and assessed.

Environmental justice, in the context of LCFs, centers on supporting the economic and social development of local communities while avoiding perpetuating disproportionate harms to these communities. Environmentally-just LCF systems ensure that communities are meaningfully consulted, are not subjected to increased pollution or land pressures, and are able to share in system benefits. It is important that community involvement is equitable, inclusive, accessible, and that it centers perspectives from vulnerable or marginalized communities.

Social and environmental harms and benefits are closely interwoven. Harms and benefits that primarily impact ecosystems are discussed under the *Environmental harms and benefits* principle.

PRODUCERS MUST

- Identify and evaluate potential social harms and benefits across the system.
- Ensure that the system does not exacerbate existing or create new social harms (e.g., adverse community health impacts) on proximate and marginalized communities.
- Develop and maintain a monitoring and mitigation strategy for all identified social harms, with particular attention to potential harms assessed as high risk or high impact.
- Ensure that communities within the system are not or will not be displaced, either through physical displacement or through displacement of income-generating activities (e.g., farming, fishing, forestry, or other local livelihoods); where displacement cannot be avoided, develop and implement a plan to provide alternative livelihoods or compensation for affected community members with the free, prior, and informed consent of those communities.
- Avoid developing on, sourcing from, disturbing, or restricting access to land legally designated as culturally sensitive. For lands not legally designated but identified by communities and local stakeholders as culturally or ecologically significant, develop and implement a mitigation strategy in consultation with those stakeholders to prevent adverse impacts.
- Adhere to relevant international, country, state, and local protocols for community consultation (e.g., free, prior, and informed consent; State of California Tribal Consultation Laws; Government of Canada Public Consultations; etc.).
- Comply with relevant international, country, state, and local laws related to benefit-sharing agreements with local communities.
- Develop and maintain a community engagement plan that gathers local stakeholder input, including Indigenous peoples if present.
    - The engagement plan must fall into the “Involve” category for “new” LCF systems and must fall into the “Inform” category for existing LCF systems, according to categories defined by the Movement Strategy Center’s Spectrum of Community Engagement.[3]

3 Movement Strategy Center. 2021. The Spectrum of Community Engagement to Ownership. [accessed 2026 May 4]. https://movementstrategy.org/wp-content/uploads/2021/08/The-Spectrum-of-Community-Engagement-to-Ownership.pdf

- Provide evidence that worker compensation is in compliance with local, state, country, and international labor laws and standards for the LCF system.
    - For the LCF production facility, specifically document individual-level worker compensation, including how compensation fits within the microeconomics of the region and demonstrate that workers receive a living wage for that region.
- Require transparent reporting of worker-related health and safety hazards and associated mitigation strategies across the LCF system.
    - For the LCF production facility, specifically document any worker-related health and safety hazards and mitigation strategies, utilizing resources established by workplace safety professionals and organizations (e.g., Occupational Safety and Health Administration) to inform mitigation measures, training procedures, and reporting channels.
- Require supply chain partners to maintain workplace injury and incident response plans in line with local and national protocols.
    - For the LCF production facility, demonstrate development and maintenance of a workplace injury and/or incident response plan in line with local and/or national protocols.

Gevo biofuel production facility. Source: Gevo.

PRODUCERS SHOULD

- Track all claimed social benefits of the LCF system in the monitoring plan using appropriate indicators. Provide robust, verifiable evidence to substantiate any social benefit claims.
- Promote long-term sustainable livelihoods and economic opportunities for local communities. This can include providing non-monetary benefits, such as education, job training, and local infrastructure improvements (e.g., road improvements).
- Clearly articulate the distributive equity of social benefits to ensure underserved, marginalized, and vulnerable populations are involved, economically empowered, and generating wealth.
- Allocate a portion of revenues or profits from LCF sales to be reinvested into the local community and other local stakeholders. Specify the form of these payments (e.g., direct payments, funding for community services or infrastructure, etc.) and clearly outline the timing of these payments.

Environmental harms and benefits

Environmental harm is defined as any result of human activity that has the effect of degrading the environment, whether temporarily or permanently. Minimizing environmental harms involves preventing and mitigating negative impacts on environmental systems. Common classes of harms seen with LCF systems include the release of pollutants into air, soil, and water, as well as thermal pollution. Because concerns vary by LCF pathway, the harms that follow are not exhaustive; rather, they highlight several of the common and potentially negative impacts that may arise across different LCF pathways.

In addition to preventing and mitigating harms, high-quality systems should strive to promote environmental benefits by enhancing underlying ecological and environmental functions, such as increasing soil health at sites where biomass is grown. Social and environmental harms and benefits are often closely interwoven. Harms and benefits that primarily impact communities and people are discussed under the *Social harms, benefits, and environmental justice* principle.

PRODUCERS MUST

- Obtain and maintain all required legal permits and operating permissions from the appropriate local, state/province, and national regulatory authorities.
- Disclose any known history of permit or regulatory violations and provide a root cause analysis of why the violation occurred, how it was remediated, and how future violations will be avoided.
- Conduct a screening-level risk assessment across the system's supply chain to identify activities with the potential for significant negative environmental impacts (e.g., on soil health, biodiversity, water resources, etc.). Document the likelihood, severity, and location of identified risks. Document ongoing efforts with supply chain partners to develop and implement appropriate mitigation and monitoring procedures for all identified risks.
  - For the LCF production facility, develop and implement a documented monitoring and mitigation plan for acute environmental impacts (e.g., fires, chemical spills) and chronic impacts (e.g., air emissions, wastewater discharge).
  - For the LCF production facility, develop and implement a remediation plan for identified environmental impacts with clearly defined thresholds that trigger actions. The plan should outline specific remediation steps to take when those thresholds are exceeded.
- Regularly inform the local community of identified environmental risks and measures taken to mitigate and monitor them.
- Transparently report the use of toxic and/or persistent environmental pollutants (e.g., industrial chemicals, pesticides, etc.) and document their potential risks.
- Adopt supply chain strategies that minimize adverse air, water, and land impacts, including waste handling and disposal activities associated with the system.
- Document robust evidence for claims of environmental benefits resulting from the LCF system.

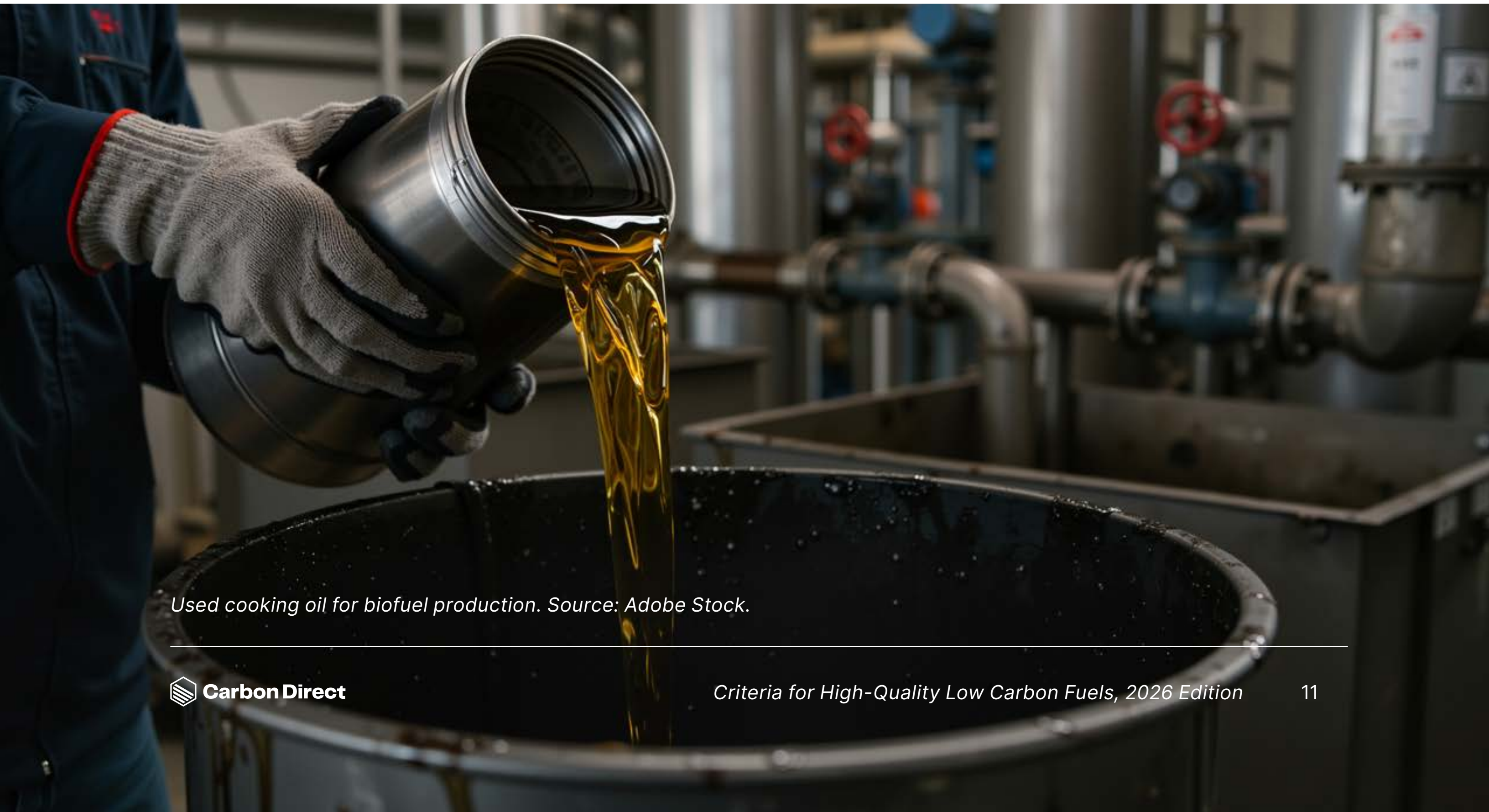
PRODUCERS SHOULD

- Establish clearly defined and quantified goals for reducing negative environmental impacts and improving sustainability outcomes, relative to the system's current operational performance, and implement a plan for monitoring and reporting progress against these goals.

- Assess pollution burdens, water use, and other resource-intensity impacts that might arise from increased demand for LCFs, relative to the resource intensity of conventional fuels. Evaluate these impacts in the context of the broader market and quantify cumulative or systemic effects.
- Prioritize sourcing from local suppliers to reduce emissions and environmental risks associated with long-distance supply chains.
- Implement measures to improve industrial sustainability, such as water recycling/reuse, heat recovery, waste valorization, and reductions in the energy intensity of fuel production to further minimize non-carbon environmental impacts.

Carbon accounting

LCF system-level carbon accounting reports all GHG emissions associated with the production and use of an LCF, using repeatable and verifiable quantification methods. In general, this requires the use of a well-to-wheel life cycle assessment (LCA) that estimates the carbon intensity (CI) of the fuel using reasonable and conservative assumptions. Assumptions are then refined once production begins and direct measurements become available. In the transportation sector, a well-to-wheel LCA is used to describe the entire life cycle of the fuel, synonymous with a cradle-to-grave LCA for other systems.



Used cooking oil for biofuel production. Source: Adobe Stock.

Regulatory schemes may differ in how they require calculation of a fuel's CI, including what factors are assessed and how attributional and consequential analyses are incorporated into a fuel's CI score. This section outlines voluntary market best practices for carbon accounting, focusing on a comprehensive approach that accounts for attributional and consequential impacts across a fuel's supply chain to enable full disclosure to a buyer.

Attributional analysis accounts for directly measurable well-to-wheel GHG impacts caused by LCF production. Consequential analysis measures indirect carbon impacts resulting from the production of LCFs, such as land use change or market displacement of feedstocks or analogous products. Both attributional and consequential impacts are important to assess when developing high-quality LCF systems. Attributional and consequential impacts are addressed in this section. Consequential impacts are further discussed under the *Leakage* principle.

PRODUCERS MUST

- Conduct an LCA that adheres to best practices (e.g., International Organization for Standardization [ISO] standards 14040 and 14044), and use a well-to-wheel system boundary that is inclusive of the system lifetime. Base the LCA on primary data where available and justify assumptions and values that are derived from literature or databases. Conduct sensitivity analyses for values with high uncertainty.
    - Clearly outline emission allocation methods for coproducts, including a sensitivity analysis on allocation assumptions and different product scenarios.
- Assess and transparently disclose relevant consequential GHG impacts associated with LCF production. These impacts may be positive (e.g., displacement of conventional products with LCF coproducts) or negative (e.g., land use change, feedstock displacement).
    - Provide detailed accounting and justification of counterfactuals for sourced feedstocks. Where the system excludes all or part of the emissions associated with the feedstock sourcing supply chain (e.g., forest management practices), the selected counterfactual scenario that supports this exclusion must be justified.
- Ensure that claimed LCF GHG reduction credits represent a net carbon-reduction outcome against a credible baseline, derived from a defensible market analysis of the

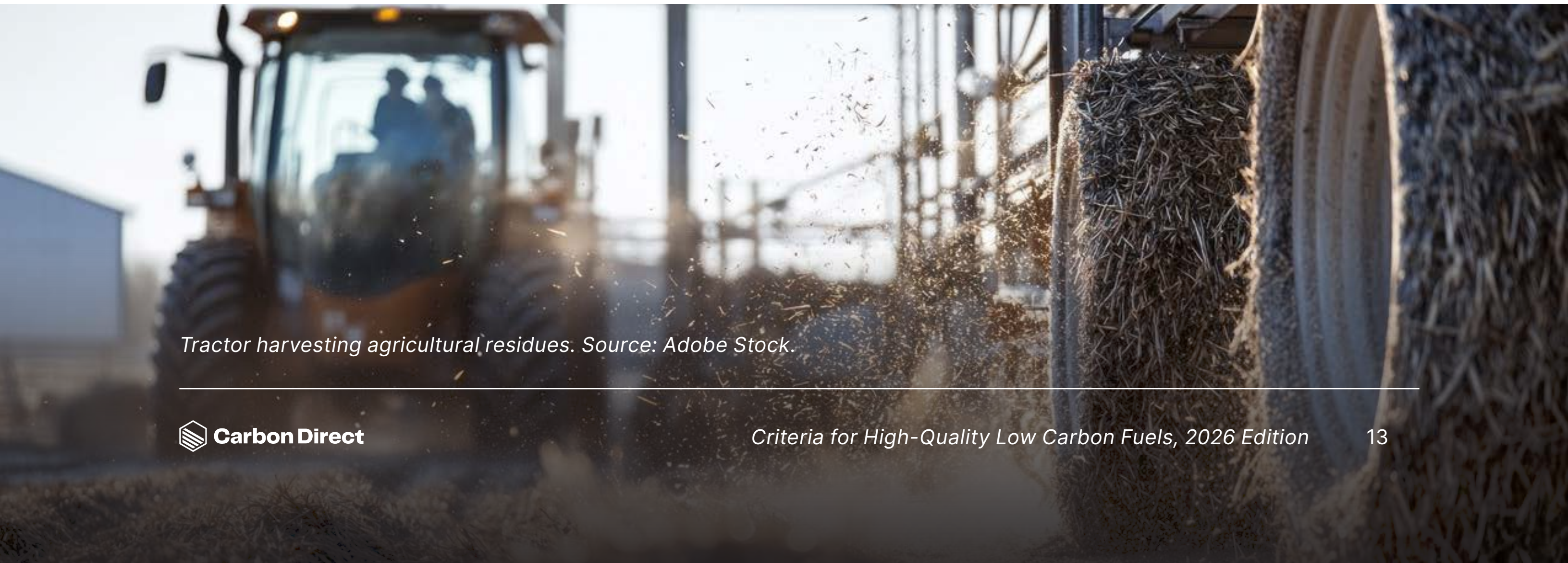
fuels that the LCF will compete with or displace. The analysis should consider relevant market characteristics, including but not limited to geographic scope, current and projected fuel types, and scale (e.g. regional, global, etc.).

  - Conduct a sensitivity analysis to ensure that quantified carbon reduction benefits are not erased by margins of error or sensitivities on key assumptions.

- Establish a regular cadence for updating the LCA and incorporate this schedule into the fuel's supply chain monitoring to ensure that carbon accounting remains closely aligned with operations, data, and emerging science.
- Ensure that fuel environmental attributes are tracked and retired through a registry that uses a third-party verified, credible carbon accounting methodology (e.g., ISO standards 14040 and 14044, Greenhouse Gas Protocol Project Accounting, etc.) and market mechanisms approach (e.g., book-and-claim or mass balance) to prevent double issuance and double claiming of attributes for the same emissions scopes (e.g., only one entity may claim the scope 1 benefits of LCF use).

PRODUCERS SHOULD

- Prioritize energy and material sources with the lowest fossil GHG emissions where multiple viable configurations are available.
- Estimate the net emissions impact that the facility's electricity procurement has on the grid, for LCF production facilities where electricity is a significant energy input. This includes assessing whether the facility's electricity consumption induces marginal grid emissions. Where a facility procures electricity through instruments such as power purchase agreements or renewable energy certificates, assess whether that procurement results in additional renewable generation that would not have occurred absent the facility's demand.



Tractor harvesting agricultural residues. Source: Adobe Stock.

Additionality

In the context of LCFs, additionality focuses on ensuring that the procurement of LCFs and associated environmental attributes support the production of renewable fuel volumes or further improvements in a fuel's carbon impacts (e.g., lower CI) that would not have occurred without voluntary market support for LCF production.

Additionality criteria focus on the differential outcomes induced by voluntary market support. The quantification of LCF performance relative to fossil fuel baselines is addressed under the *Carbon accounting* principle, where emissions reductions are quantified by comparing the CI of the LCF to the CI of an appropriate fossil fuel baseline.

PRODUCERS MUST

- Demonstrate that revenue from the voluntary market is required to enable favorable outcomes that would not otherwise occur in the absence of such support. This includes the use of financial metrics, such as internal rate of return or profitability, to show that the production of additional LCF volumes and associated environmental attributes (i.e., increased volumes at the same or similar CI) and/or expenditures that further reduce a fuel's CI (i.e., lower CI with the same or similar fuel volumes) are not viable without voluntary market support.
    - For new fuel supply chains, demonstrate that voluntary market support enables production of fuel volumes that would have not been produced without carbon finance. When multiple financing streams support an LCF system, the system is considered financially additional if revenue deriving from sale of the fuel's environmental attributes are necessary for the fuel volumes to be produced.
    - For existing fuel supply chains, demonstrate that revenue from the voluntary market is required to produce incremental increases in fuel volumes and associated environmental attributes and/or reduce the fuel's CI.
- For systems participating in regulatory programs, full financial information must be provided to demonstrate that financial additionality is met when accounting for any tax credits (e.g., 45Z Clean Fuel Production Credit), government subsidies and grants, regulatory incentives (e.g., Renewable Fuel Standard Renewable Identification Numbers, Low Carbon Fuel Standard credits) and any other public or policy-driven financial support. This is particularly important where multiple revenue streams are present.

- Demonstrate that the production of the LCF and its environmental attributes is not mandated by existing or enforced laws, regulations, or other binding obligations.

PRODUCERS SHOULD

Conduct a sensitivity analysis on key financial model variables (e.g., costs, tax credits, subsidies, etc.) to determine how these variables impact the price at which the low carbon fuel and associated environmental attributes must be sold to maintain financial viability of production.

Feedstock sourcing

This section covers the sustainability and supply-chain integrity requirements of LCF feedstocks. The scope of these criteria is limited to biogenic feedstocks used to produce LCFs for transportation. The specific feedstock categories covered under this principle, and those excluded from this edition, are as follows:

- **In scope:** agricultural-derived biomass and residues, forestry-derived biomass and residues, and waste oils (e.g., used cooking oil, tallow)
- **Out of scope:** manure-based feedstocks and feedstocks derived from municipal solid waste

Carbon Direct has published two guides that establish sourcing principles for biomass used in CDR applications: the *Sustainable Forest Biomass Sourcing for CDR: A Buyer's Guide*,[4] which covers forestry-derived biomass and residues, and the *Buyer's Guide to Sustainable Agricultural Biomass Sourcing*,[5] which covers agricultural residues. These guides provide detailed requirements related to on-site environmental practices, soil and forest health, biodiversity, labor conditions, and community protections, and are relevant reference points for buyers and producers sourcing these feedstock types for LCF production.

The criteria below are not intended to replicate or replace those guides. Rather, they represent the sustainability and supply-chain integrity guidelines most directly applicable to LCF feedstock sourcing. They are designed to reflect the realities of the LCF market, which currently sources a broader range of feedstocks than either guide addresses.

4 Carbon Direct. 2025. Sustainable Forest Biomass Sourcing for CDR: A Buyer's Guide. [accessed 2026 May 4]. https://www.carbon-direct.com/research-and-reports/2025-guide-to-sustainable-biomass-sourcing

5 Carbon Direct. 2026. Buyer's Guide to Sustainable Agricultural Biomass Sourcing. [accessed 2026 May 28]. https://www.carbon-direct.com/research-and-reports/agricultural-biomass-sourcing-for-cdr-2026.

Additionally, both guides were developed with CDR buyers and project developers as the primary audience. Where their principles inform LCF sourcing decisions, users should apply them with appropriate judgment to account for differences in feedstock use, market structure, and supply chain dynamics between the CDR and LCF markets. Producers must ensure that biomass feedstocks are sourced in accordance with the following guidelines:

PRODUCERS MUST

- Source from biomass suppliers that operate with integrity and oversight through strong governance, standards, and supply-chain transparency.
- Utilize biomass supply chains that minimize negative impacts on Indigenous peoples, workers, and local communities.
- Procure biomass without threatening protected areas or reducing regional carbon stocks.
- Maintain a documented chain-of-custody system that enables buyers to verify the geographic origin, supplier identity, and batch-level sourcing of feedstocks for end-to-end supply-chain traceability.
    - Require feedstock aggregators to maintain documentation that tracks feedstocks back to the point of generation. This evidence must be trackable through collection, aggregation, and processing.
    - Require agricultural feedstock suppliers to maintain field-level traceability records including history of cultivation and production practices.

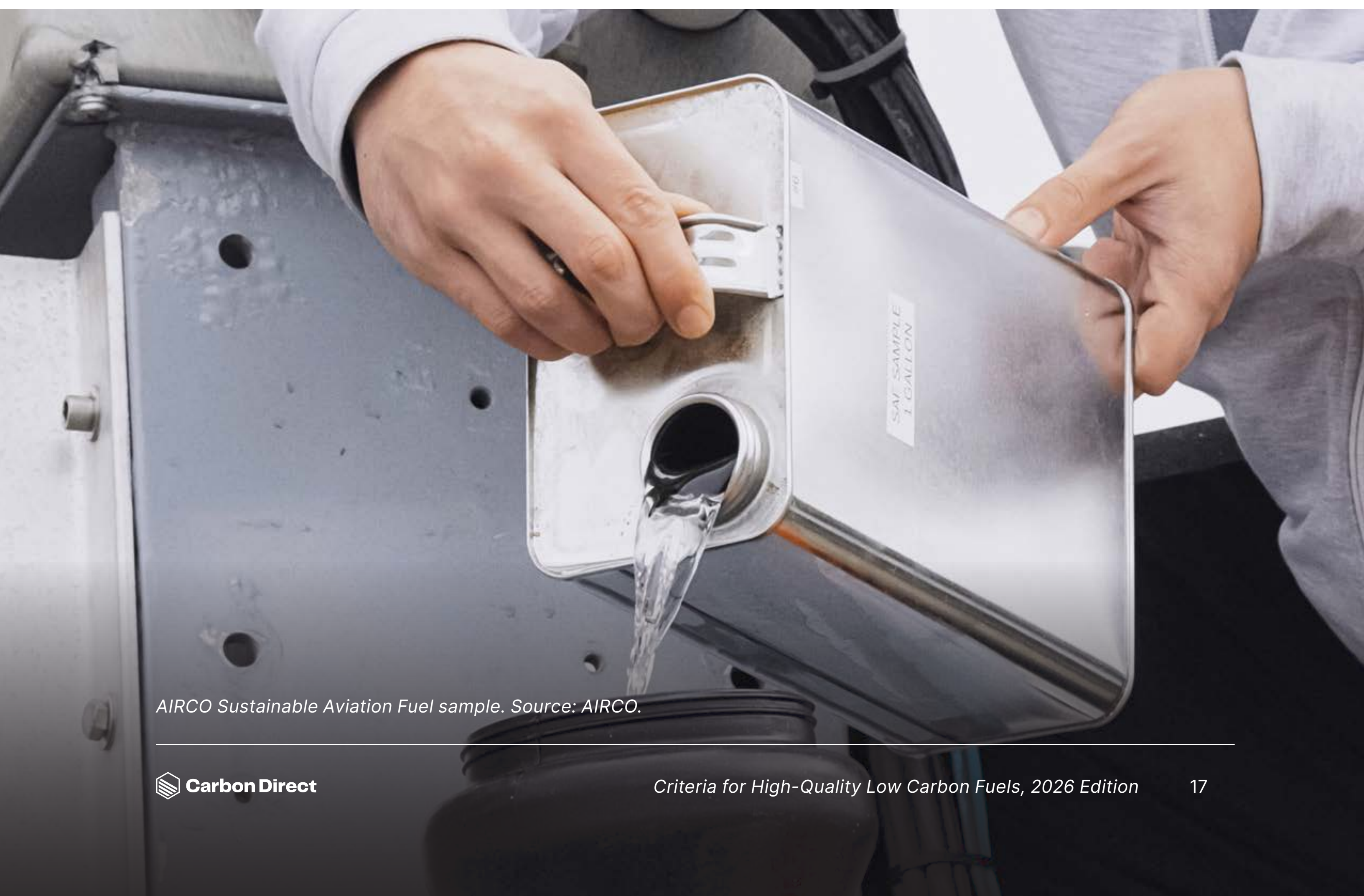
PRODUCERS SHOULD

- Prioritize sourcing local or regionally accessible feedstocks to support effective operational oversight and enhance transparency across the feedstock supply chain.
- Encourage the use of digital geospatial tools (e.g., satellite monitoring, ledger systems, geotagged transport documentation, etc.) to improve feedstock traceability and transparency.
- Encourage supplier participation in industry-wide initiatives to prevent fraud, including shared databases (e.g., registries), verification coalitions, or traceability networks.
- Encourage and provide support to feedstock suppliers to adopt production practices that enhance soil health, reduce production emissions, and limit negative environmental impacts.

Leakage

Economic leakage, often referred to as displacement, occurs when an LCF system's activities cause emissions to increase in another location, time, or form, which can negate the intended carbon reduction benefits of the system. Economic leakage occurs because the LCF system decreases the local supply of goods and services by displacing existing activities, such as through production shifts or land-use changes. Typically, when prior market demand does not change, these activities simply move elsewhere and create emissions outside the LCF system boundary.

There are two primary types of economic leakage: activity-shifting leakage and market leakage. Activity-shifting leakage occurs when production activities within the fuel's supply chain do not stop but are instead relocated outside the system boundary. Market leakage occurs when an LCF system alters market conditions, such as reducing the available supply of a good or increasing demand, such that unmet demand is met through increased activity elsewhere, potentially leading to higher emissions. These effects may arise through price signals or other market responses and are often difficult to predict or quantify.



AIRCO Sustainable Aviation Fuel sample. Source: AIRCO.

PRODUCERS MUST

- Conservatively assess sources of market leakage associated with the LCF system, across domestic and international markets, including impacts from land use change, feedstock sourcing, displacement of bio-based product markets, and consumption or displacement of regional materials and energy supplies.
- Conservatively account for any activity-shifting leakage within the LCF system boundary.
- Document all potential sources of leakage and implement mitigation strategies to minimize leakage outcomes over the lifetime of the LCF system.

PRODUCERS SHOULD

- Avoid reliance on feedstocks with the potential for land-use change impacts.
- Avoid distortion of existing markets for agricultural or forestry products (e.g., pulp and paper).
- Design LCF systems to avoid inducing activity-shifting leakage.
- Prioritize suppliers with a demonstrated track record of improving feedstock collection efficiency or developing new collection technologies that expand overall feedstock supply without diverting materials from existing uses.
- Evaluate how the LCF system's feedstock sourcing strategy aligns with and impacts the broader expansion of the LCF market. Consider global feedstock availability, competing uses, and potential impacts on land use, deforestation, biodiversity, and food and commodity markets.
- If participating in an existing regulatory framework, evaluate any potential consequences of that participation, including how the framework addresses land-use change risks associated with feedstock sourcing.
- Assess whether the procurement of feedstocks may create risks of displacement from existing uses or introduce incentive structures with unintended consequences. If a feedstock is procured at a non-zero cost, provide a clear justification for the price paid and explain how it avoids incentivizing displacement or adverse market impacts.

Glossary of technical terms

The following terms are used throughout the *2026 Criteria for High-Quality Low Carbon Fuels*. Definitions are derived from how terms are used within the document and are provided to support consistent interpretation of the criteria across LCF pathways and supply-chain contexts. Terms are listed in alphabetical order.

Activity-shifting leakage: A type of economic leakage that occurs when production activities within a fuel's supply chain do not stop but are instead relocated outside the LCF system boundary, resulting in emissions that are not captured by the system's carbon accounting.

Additionality: The principle that the procurement of LCFs and associated environmental attributes must support renewable fuel volumes or improvements in carbon intensity that would not have occurred absent voluntary market support for LCF production.

Attributional analysis: A method that estimates and attributes life cycle environmental burdens (including greenhouse gas emissions) of a LCF product system to all its products and/or functions.

Biofuel: A fuel derived from biogenic (biological) feedstocks, such as agricultural biomass, forestry residues, or waste oils. In this document, biofuels for transportation are the primary focus, as they comprise the majority of current LCF production and use.

Biogenic feedstock: Organic material of biological origin used as an input to LCF production. Biogenic feedstocks covered in this document include agricultural-derived biomass and residues, forestry-derived biomass and residues, and waste oils (e.g., used cooking oil, tallow).

Book-and-claim: Book and claim is a chain-of-custody model that allows environmental attributes to be decoupled from physical, lower-carbon products or services that would ordinarily directly carry those attributes. This creates a separate certificate that allows buyers without physical access to lower-carbon products or services to financially enable the decarbonization of a sector and claim its benefits.

Carbon intensity: A measure of the greenhouse gas emissions associated with the full life cycle of a LCF, typically expressed in grams of carbon dioxide equivalent per unit of energy (gCO_2e/MJ).

Chain of custody: A documented system that enables buyers to verify the geographic origin, supplier identity, and batch-level sourcing of feedstocks from the point of generation through collection, aggregation, processing, and fuel production, supporting end-to-end supply chain traceability.

Consequential analysis: A method that estimates changes in environmental impacts outside of a product system due to the activities of the product system. Such impacts related to LCF production could include land use change or market displacement of feedstocks or analogous products. Consequential impacts can be positive (e.g., displacement of conventional products with LCF coproducts) or negative (e.g., land use change).

Co-product emission allocation: The method used in an LCA to distribute GHG emissions among multiple products derived from the same LCF production process.

Counterfactual: Hypothetical scenario representing what would have occurred in the absence of a specific action that generated an environmental attribute; often the business-as-usual case is used as a counterfactual to assess additionality.

Economic leakage: The phenomenon by which an LCF system's activities cause GHG emissions to increase in another location, time, or form, potentially negating the intended carbon reduction benefits. Economic leakage can occur because the LCF system decreases the local supply of goods or services, causing displaced activities to occur elsewhere. The two primary types are activity-shifting leakage and market leakage.

Environmental attributes: Environmental attributes are characteristics of products that represent specific sustainability aspects of those products. These attributes may include carbon intensity, emissions reductions, and other sustainability characteristics. Environmental attributes may be tracked, transferred, and retired through a registry to enable voluntary market transactions.

Financial additionality: A system demonstrates financial additionality by showing, through financial metrics such as internal rate of return or profitability, that the production of additional LCF volumes or further reductions in carbon intensity are not financially viable absent revenue from environmental attribute sales.

Fossil fuel baseline: The reference fuel against which an LCF's life cycle GHG emissions are compared to determine the magnitude of carbon reduction.

Free, prior, and informed consent: A principle that requires meaningful consultation with and consent from affected communities, particularly Indigenous peoples, before initiating activities that may impact their lands, livelihoods, or cultural practices.

Functional unit: A standardized reference unit of a product or product system that directly represents the core function and performance the product delivers in its use phase.

Greenhouse gas: A gas that traps heat in the atmosphere, contributing to climate change. For the purposes of carbon accounting in this document, GHG emissions are expressed in units of carbon dioxide equivalent (CO_2e) and assessed across a fuel's full well-to-wheel life cycle.

Land use change: A consequential GHG impact that occurs when land is converted from one use to another (e.g., from forest or grassland to cropland for feedstock production), thereby releasing stored carbon into the atmosphere.

LCF system: The full set of production, certification, and procurement arrangements through which LCFs are generated and claimed. LCF systems encompass not only individual projects and production facilities but also fuel blenders, coordinators, aggregators, and certificate traders.

Life cycle assessment: A methodology used to evaluate the GHG emissions and other environmental impacts associated with the production and use of a fuel across its entire life cycle.

Low carbon fuel: An energy carrier whose life cycle GHG emissions are lower than those of a relevant and use-case-specific fossil fuel baseline. For the purposes of this document, the term refers to physical biofuel and its associated environmental attributes. LCFs may be produced through biogenic, synthetic, or other non-fossil pathways.

Market leakage: A type of economic leakage that occurs when an LCF system alters market conditions, such as reducing the available supply of a good or increasing demand, such that demand is met through increased activity elsewhere, potentially leading to higher emissions.

Mass balance: A chain-of-custody method which accounts the movement of materials into, out of, and within a system to allow the blending of lower-carbon products with conventional products.

Point source: The location within the supply chain where a feedstock is originally generated.

Regulatory additionality: A metric which establishes that the climate benefits associated with a project go beyond what is already required by law or regulation. LCFs and associated environmental attribute certificates fulfill regulatory additionality only if they support voluntary actions that exceed existing policy mandates.

Renewable natural gas: A gaseous fuel primarily composed of methane produced from organic waste materials. RNG is excluded from the scope of this edition of the LCF criteria.

Spectrum of Community Engagement: A framework developed by the Movement Strategy Center that describes different levels of community involvement, ranging from informing communities to full collaborative governance.

Voluntary market: The market through which buyers and sellers transact LCFs and associated environmental attributes outside of mandatory regulatory compliance requirements.

Waste oil: A category of biogenic feedstock that includes used cooking oil, tallow, and other lipid-based products.

Well-to-wheel: A life cycle system boundary used to encompass all GHG emissions from the extraction or generation of the feedstock through the end use of the fuel (i.e., combustion in a vehicle engine). This boundary is synonymous with cradle-to-grave for other product systems.

Authorship and acknowledgements

The Carbon Direct team that developed this report comprised: Rohan Raman (Lead Author); Joe Willenborg; Hannah Williams; Ameya Sampath; Dr. John Dees; Avantika Singh; Dr. Erica Belmont; Dr. Matthew Potts; Dr. Zara Ahmed; Dr. Grant Gutierrez; Adrianna Sutton; Britt Warthen

We thank the following experts for their foundational input to this guidance: Dr. Colin Murphy (University of California Davis Institute of Transportation Studies); Dr. Kevin Fingerman (California State Polytechnic University, Humboldt), Dr. Chris Malins (Cerulogy)

We thank the following stakeholders for their active engagement and feedback (stakeholders are listed alongside their organization at the time of consultation): Adam Klauber (World Energy); Morgan Sparkes (AIRCO); Gregory Constantine (AIRCO); James Mackey (AIRCO); Matthew Cauthen (AIRCO); Matthew Viergutz (Velocys); Dave Astrauckas (Kolmar Americas); Stephen Johnson (Illinois Clean Fuels); Erin L. Heitkamp (Gevo); Alex Clayton (Gevo); Nancy Young (Gevo); Taylor F Wright (JPMorganChase); Siya Piparsania (JPMorganChase); Connor Cobb (JPMorganChase)

Cover image: Aerial view of biofuel production facility. Source: iStock.