1.0
version

Methodology for the Production and Verification of Ethanol Quantified Emissions Tokens® (QET-Ethanol) in Accordance with ISO 14064-3

This methodology extends the core QET framework to ethanol production, addressing process-specific characteristics including biological fermentation, synthetic production pathways, and diverse feedstock sources.

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Q Ethanol

Methodology for the Production and Verification of Ethanol Quantified Emissions Tokens® (QET-Ethanol) in Accordance with ISO 14064-3

This methodology document establishes a comprehensive, verifiable framework for the production and verification of Quantified Emissions Tokens® (QETs) for ethanol production, in accordance with ISO 14064-3 verification standards. The QET-Ethanol methodology extends the core QET framework to address the unique characteristics of ethanol production processes, including biological fermentation, synthetic production pathways, and diverse feedstock sources.

Key Objectives

1. **Establish ethanol-specific QET production processes** that capture memissions across the full ethanol lifecycle from feedstock cultivation through fermentation, distillation, and distribution.
2. **Define verification procedures** for QET-Ethanol tokens that meet ISO 14064-3 standards while addressing the complexity of biological and thermochemical conversion processes.
3. **Create standardized data structures** for ethanol production attributes, including feedstock type, conversion pathway, carbon intensity, and co-product allocation.
4. **Ensure compatibility** with existing LCFS compliance frameworks and other regulatory programs while maintaining methodology independence.

This methodology is designed to be pathway-agnostic, supporting verification of ethanol produced from sugar-based feedstocks (sugarcane, sugar beet), starch-based feedstocks (corn, wheat), cellulosic feedstocks (agricultural residues, energy crops), and synthetic routes (syngas-to-ethanol).

1. Scope

1.1 Application Scope

This methodology applies to the quantification, verification, and tokenization of greenhouse gas emissions associated with ethanol production from all recognized feedstock pathways and production processes. The scope encompasses:

Production Pathways Covered:

- Biological fermentation-based ethanol production from sugar feedstocks (sugarcane, sugar beet, sweet sorghum)
- Biological fermentation-based ethanol production from starch feedstocks (corn, wheat, cassava, grain sorghum)
- Cellulosic ethanol production from lignocellulosic biomass (agricultural residues, forestry residues, energy crops)
- Synthetic ethanol production via syngas fermentation or catalytic conversion
- Advanced fermentation processes using engineered microorganisms

Lifecycle Boundaries:

- Feedstock cultivation and harvesting (including land use change considerations)
- Feedstock transportation to ethanol production facility
- Feedstock preprocessing (milling, enzymatic hydrolysis, pretreatment)
- Fermentation process emissions
- Distillation and dehydration energy consumption
- Co-product generation and allocation (DDGS, lignin, bagasse, stillage)
- Facility energy consumption (thermal and electrical)
- Wastewater treatment emissions
- On-site fugitive emissions
- Distribution to fuel blending terminals (optional boundary extension)

1.2 Exclusions

The following are explicitly excluded from this methodology unless specifically included by mutual agreement between QET Producer and Verifier:

- End-use combustion emissions (tailpipe emissions)
- Infrastructure construction emissions (amortized over facility lifetime)
- Employee commuting and business travel
- Indirect land use change (iLUC) unless required by applicable regulatory framework
- Downstream blending and distribution beyond the facility gate

1.3 Functional Unit

The functional unit for QET-Ethanol methodology is **one gallon of anhydrous ethanol** (or volumetric equivalent in liters) at standard conditions (60°F, 1 atm), expressed as **kgCO_2e per gallon**.

Physical Properties and Standards:

- 1 gallon anhydrous ethanol = 3.78541 liters
- Density: 0.789 kg/liter (anhydrous ethanol at 20°C)
- Mass per gallon: 2.987 kg
- Energy content (LHV): 76,330 BTU/gallon = 80.53 MJ/gallon

Token Representation:

QET-Ethanol tokens are issued on a **mass basis** aligned with EARN DLT's mass-based QET classification. Each token represents **one kilogram (1 kg)** of verified ethanol production. For practical use:

- 1 QET-Ethanol token = 1 kg of anhydrous ethanol
- 1 gallon anhydrous ethanol = 2.987 kg ≈ 2.987 tokens (issued as whole kg units)
- 1,000 gallons = 2,987 kg = 2,987 tokens

Carbon Intensity Expression:

Carbon intensity is expressed in multiple units to serve different stakeholder needs:

1. **Primary (Producer/Industry):** kgCO_2e per gallon
2. **Regulatory (LCFS/RFS/RED):** gCO_2e per MJ
3. **Per Token Basis:** kgCO_2e per kg (for token metadata)
4. **Mass-Specific:** gCO_2e per kg (for scientific applications)

Conversion Factors:

$$kgCO_2e/kg = \frac{kgCO_2e/gallon}{2.987\ kg/gallon}$$

$$gCO_2e/MJ = \frac{kgCO_2e/gallon \times 1000}{80.53\ MJ/gallon}$$

Registry Platform Alignment:

This structure aligns with EARN DLT's mass-based QET pricing for chemical products, liquid fuels, and refined products, where network infrastructure fees are assessed per kilogram of verified product mass. The gallon functional unit preserves industry-standard reporting while enabling efficient blockchain tokenization and transaction processing.

1.4 Compatibility with Regulatory Frameworks

This methodology is designed to support, but not mandate, compliance with:

- California Low Carbon Fuel Standard (LCFS)
- Federal Renewable Fuel Standard (RFS)
- Oregon Clean Fuels Program
- Canadian Clean Fuel Regulations
- European Union Renewable Energy Directive (RED II/III)
- International Sustainability and Carbon Certification (ISCC)

When QET-Ethanol tokens are produced for compliance purposes, the appropriate QET-Extension Methodology must be applied in conjunction with this document.

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2. Normative References

The following documents are indispensable for the application of this methodology:

2.1 ISO Standards

- **ISO 14064-1:2018** – Greenhouse gases — Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals
- **ISO 14064-2:2019** – Greenhouse gases — Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements
- **ISO 14064-3:2019** – Greenhouse gases — Part 3: Specification with guidance for the verification and validation of greenhouse gas statements
- **ISO 14065:2020** – General principles and requirements for bodies validating and verifying environmental information
- **ISO/IEC 17029:2019** – Conformity assessment — General principles and requirements for validation and verification bodies
- **ISO 14080:2018** – Greenhouse gas management and related activities — Framework and principles for methodologies on climate actions

2.2 QET Framework Documents

- **Methodology for the Production and Verification of Quantified Emissions Tokens® (QETs) in Accordance with ISO 14064-3** (Core Methodology) – Version 2.0 or later
- **Methodology for the Production and Verification of Low Carbon Fuel Standard Quantified Emissions Tokens® (QET-LCFS) in Accordance with ISO 14064-3** – Version 1.0 or later (when applicable)
- **QET Registry Operating Rules and Procedures** – Current version

2.3 Regulatory and Technical References

- **IPCC Guidelines for National Greenhouse Gas Inventories** (2006, with 2019 Refinement)
- **CA-GREET 3.0** (California-modified Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model)
- **GREET Model** (Argonne National Laboratory) – Current version
- **40 CFR Part 98** – U.S. EPA Greenhouse Gas Reporting Program (Subpart MM - Suppliers of Petroleum Products)
- **ASTM D4806** – Standard Specification for Denatured Fuel Ethanol for Blending with Gasolines
- **EN 15376** – Automotive fuels — Ethanol as a blending component for petrol
- **RSB Standard for Advanced Fuels** (Roundtable on Sustainable Biomaterials)
- **ISCC EU and ISCC PLUS Certification Standards**

2.4 Lifecycle Assessment Standards

- **ISO 14040:2006** – Environmental management — Life cycle assessment — Principles and framework
- **ISO 14044:2006** – Environmental management — Life cycle assessment — Requirements and guidelines
- **ISO 14067:2018** – Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification

3. Terms and Definitions

For the purposes of this methodology, the terms and definitions given in ISO 14064-3:2019, ISO 14065:2020, and the Methodology for the Production and Verification of Quantified Emissions Tokens® (QETs) in Accordance with ISO 14064-3 apply, along with the following ethanol-specific terms:

3.1 Ethanol Production Terms

3.1.1 anhydrous ethanol

Ethanol with maximum water content of 1% by volume (99% purity minimum), suitable for fuel blending applications

3.1.2 hydrous ethanol

Ethanol containing 4-5% water by volume, used directly as fuel in flex-fuel vehicles without further dehydration

3.1.3 fermentation

Biochemical process whereby microorganisms (typically *Saccharomyces cerevisiae*) convert sugars into ethanol and carbon dioxide under anaerobic conditions

3.1.4 distillation

The thermal separation process used to concentrate ethanol from fermentation broth, typically achieving 95% ethanol by volume

3.1.5 dehydration

Process of removing residual water from ethanol to achieve anhydrous specifications, typically using molecular sieves or azeotropic distillation

3.1.6 mashing

Process of cooking and enzymatically converting starch-based feedstocks into fermentable sugars using amylase enzymes

3.1.7 saccharification

Enzymatic or chemical hydrolysis of complex carbohydrates (starch, cellulose) into simple sugars suitable for fermentation

3.1.8 pretreatment

Physical, chemical, or biological treatment of cellulosic biomass to disrupt lignin-carbohydrate matrix and enhance enzymatic accessibility

3.1.9 syngas fermentation

Process of converting synthesis gas (CO, H_2, CO_2) into ethanol using acetogenic bacteria or engineered microorganisms

3.2 Feedstock Terms

3.2.1 first-generation feedstock

Sugar- or starch-based feedstocks derived from food crops (corn, sugarcane, wheat, sugar beet)

3.2.2 second-generation feedstock

Cellulosic biomass feedstocks, including agricultural residues (corn stover, wheat straw), forestry residues, and dedicated energy crops (switchgrass, miscanthus)

3.2.3 advanced feedstock

Non-food feedstocks including municipal solid waste, industrial waste gases, algae, or other innovative feedstock sources as defined by regulatory frameworks

3.2.4 energy crop

Perennial or annual crop grown specifically for energy production rather than food, feed, or fiber

3.2.5 agricultural residue

Biomass remaining after primary agricultural product harvest, including corn stover, wheat straw, rice hulls, and sugarcane bagasse

3.3 Co-Product Terms

3.3.1 distillers dried grains with solubles (DDGS)

Co-product of corn ethanol production consisting of concentrated protein, fiber, and oil, used primarily as livestock feed

3.3.2 wet distillers grains (WDG)

Non-dried co-product from ethanol distillation with approximately 65-70% moisture content

3.3.3 bagasse

Fibrous residue remaining after sugar extraction from sugarcane, typically used for energy generation or as cellulosic feedstock

3.3.4 lignin

Organic polymer co-product from cellulosic ethanol production, typically used for energy generation or as chemical feedstock

3.3.5 stillage

Liquid residue remaining after ethanol distillation, containing dissolved solids, yeast, and unconverted sugars

3.4 Carbon Intensity Terms

3.4.1 carbon intensity (CI)

Total lifecycle greenhouse gas emissions per unit of energy delivered, expressed as gCO_2e/MJ for ethanol fuel

3.4.2 direct emissions

GHG emissions from sources owned or controlled by the ethanol production facility, including combustion, fermentation, and process emissions

3.4.3 indirect emissions

GHG emissions resulting from facility activities but occurring at sources not owned or controlled by the facility, including purchased electricity and feedstock cultivation

3.4.4 biogenic carbon

Carbon dioxide absorbed from the atmosphere during feedstock growth and released during fermentation or combustion, considered carbon-neutral in most accounting frameworks

3.4.5 co-product allocation

Methodology for dividing lifecycle emissions between ethanol and co-products based on energy content, market value, or displacement ratios

3.5 QET-Ethanol Specific Terms

3.5.1 QET-Ethanol

A Quantified Emissions Token representing the verified greenhouse gas emissions associated with **one kilogram (1 kg)** of ethanol produced according to this methodology. Each gallon of anhydrous ethanol generates approximately 2.987 tokens (issued as whole kg units).

3.5.2 mass-based QET

A QET denominated in kilogram (kg) units, applicable to chemical products, liquid fuels, petrochemicals, refined products, and manufactured goods. Mass-based QETs enable standardized transaction processing for commodities traded by weight or mass within the EarnDLT® platform.

3.5.3 functional unit (ethanol-specific)

One gallon of anhydrous ethanol serving as the reference unit for carbon intensity calculations and industry reporting, while tokens are issued on a per-kilogram mass basis for registry operations.

3.5.4 token conversion factor

The relationship between volumetric production (gallons) and mass-based tokens, calculated as:

$$Tokens = Gallons \times 2.987\ kg/gallon$$

3.5.5 carbon intensity per token

The greenhouse gas emissions per kilogram of ethanol, calculated by dividing total allocated emissions by total mass produced, expressed as $kgCO_2e/kg$ or gCO_2e/kg.

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4. General Requirements for QET-Ethanol Production

4.1 Fundamental Principles

The production of QET-Ethanol tokens shall adhere to the following fundamental principles established in the Methodology for the Production and Verification of Quantified Emissions Tokens® (QETs) in Accordance with ISO 14064-3:

4.1.1 Relevance

QET-Ethanol tokens shall appropriately reflect the GHG emissions of ethanol production and serve the decision-making needs of stakeholders, including fuel blenders, compliance entities, and end consumers.

4.1.2 Completeness

All relevant GHG emissions sources within the defined system boundary shall be accounted for and disclosed. Any exclusions must be justified and documented.

4.1.3 Consistency

Methodologies shall be applied consistently across reporting periods to enable meaningful comparisons. Any changes in methodology, data quality, or system boundaries must be transparently documented.

4.1.4 Accuracy

Quantification shall be sufficiently accurate to enable stakeholders to make decisions with reasonable confidence. Bias and uncertainty shall be reduced as far as practicable.

4.1.5 Transparency

All relevant assumptions, calculation methodologies, data sources, and uncertainty assessments shall be disclosed to enable verification and stakeholder review.

4.1.6 Conservativeness

Where uncertainty exists, conservative assumptions shall be applied to avoid understating emissions or overstating emissions reductions.

4.2 Eligibility Requirements

4.2.1 Facility Registration

Ethanol production facilities seeking to produce QET-Ethanol tokens must:

- Register with the QET Registry system and provide facility identification information
- Maintain valid business licensing and environmental permits
- Demonstrate compliance with applicable environmental regulations
- Establish data management systems capable of tracking production volumes, feedstock inputs, and emissions sources
- Designate a responsible party with authority to certify data accuracy

4.2.2 Production Documentation

The facility must maintain comprehensive records, including:

- Daily ethanol production volumes with moisture content specifications
- Feedstock procurement records, including type, quantity, moisture content, and origin
- Energy consumption data (natural gas, electricity, coal, biomass) with meter readings
- Process emission sources (fermentation CO_2, combustion, wastewater treatment)
- Co-product generation records (DDGS, WDG, lignin, bagasse) with quantities and disposition
- Quality control laboratory results for ethanol purity
- Continuous emissions monitoring system (CEMS) data, where applicable

4.2.3 Measurement and Monitoring Infrastructure

Facilities must have or implement:

- Calibrated metering for all ethanol production outputs
- Calibrated metering for all significant energy inputs
- Weighing or volumetric measurement systems for feedstock inputs
- Emission monitoring systems meeting regulatory requirements (CEMS or equivalent)
- Laboratory facilities or contracts for feedstock and product quality analysis
- Data acquisition systems capable of hourly or daily data collection

4.3 System Boundaries

4.3.1 Temporal Boundary

QET-Ethanol tokens represent emissions from ethanol produced during a defined reporting period, typically:

- Monthly production batches (minimum)
- Quarterly reporting periods (recommended)
- Annual facility totals (for continuous production)

The reporting period must align with facility operations and allow for timely verification within 90 days of period completion.

4.3.2 Organizational Boundary

The organizational boundary includes all ethanol production operations owned or controlled by the QET Producer, encompassing:

- Feedstock receiving and storage
- Feedstock preprocessing (milling, grinding, size reduction)
- Fermentation vessels and associated equipment
- Distillation columns and dehydration systems
- Co-product separation and drying equipment
- On-site power generation or cogeneration facilities
- Wastewater treatment systems
- Product storage and loading facilities

4.3.3 Operational Boundary

The operational boundary defines which emission sources are included:

Scope 1 - Direct Emissions (Mandatory):

- Fermentation CO_2 (biogenic, reported separately)
- Combustion of natural gas, coal, or fuel oil for process heat
- Combustion of biomass residues (bagasse, lignin) for process energy
- Mobile equipment emissions (forklifts, loaders)
- Fugitive emissions from storage tanks and transfer operations
- Wastewater treatment methane and nitrous oxide emissions

Scope 2 - Indirect Energy Emissions (Mandatory):

- Purchased electricity from grid
- Purchased steam or thermal energy

Scope 3 - Other Indirect Emissions (Conditional):

- Feedstock cultivation and harvesting (mandatory for first-generation feedstocks)
- Feedstock transportation to facility (mandatory)
- Enzyme and chemical production (mandatory if >5% of total emissions)
- Co-product transportation (optional)
- Direct land use change emissions (mandatory if land converted within 10 years)
- Seed and fertilizer production for energy crops (mandatory for dedicated energy crops)

4.4 Data Quality Requirements

4.4.1 Data Hierarchy

Emission quantification shall follow this data quality hierarchy:

Tier 1 - Highest Quality (Preferred):

- Direct continuous monitoring with calibrated instrumentation
- Facility-specific emission factors from source testing
- Actual measured quantities for all inputs and outputs

Tier 2 - Medium Quality (Acceptable):

- Periodic direct measurements (monthly or quarterly)
- Industry-specific emission factors from recognized sources
- Engineering calculations based on material balance

Tier 3 - Lower Quality (Acceptable with Justification):

- Regional or national average emission factors
- Supplier-provided data with quality documentation
- Proxy data from similar operations with documented similarity

Tier 4 - Lowest Quality (Requires Approval):

- Default values from regulatory guidelines
- Literature values with documented applicability
- Conservative estimates with documented rationale

The QET Producer must document the tier level used for each significant emission source and justify any use of Tier 3 or Tier 4 data.

4.4.2 Uncertainty Management

All quantification methods shall include uncertainty assessment following ISO 14064-3 requirements. Uncertainty shall be reduced through:

- Selection of highest quality data available
- Calibration and maintenance of measurement equipment
- Implementation of quality assurance/quality control procedures
- Use of multiple data sources for cross-validation
- Statistical analysis of measurement variability

Target uncertainty levels:

- Primary outputs (ethanol volume): ±2%
- Major energy inputs: ±5%

- Process emissions: ±10%
- Indirect emissions: ±20%

4.4.3 Data Retention

All source data, calculations, and supporting documentation must be retained for a minimum of seven (7) years from the date of QET-Ethanol token issuance. Records must be accessible for verification and audit purposes.

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5. Quantification Methodology for QET-Ethanol Production

5.1 General Approach

The quantification methodology for QET-Ethanol follows a lifecycle assessment (LCA) approach consistent with ISO 14044 and ISO 14067, calculating total GHG emissions per functional unit of ethanol produced. The methodology employs a **process-based LCA** with the following steps:

1. Define system boundaries and functional unit
2. Identify all emission sources within boundaries
3. Collect activity data for each emission source
4. Apply appropriate emission factors
5. Calculate total emissions by GHG type
6. Convert to CO_2 equivalents using IPCC Global Warming Potential values
7. Allocate emissions between ethanol and co-products
8. Calculate carbon intensity per functional unit
9. Assess uncertainty and apply conservative adjustments
10. Document all assumptions and data sources

5.2 Carbon Intensity Calculation Framework

The overall carbon intensity (CI) for ethanol is calculated on a **per-gallon basis** as the primary reporting metric, with conversion to per-mass and per-energy units for token metadata and regulatory compliance.

5.2.1 Primary Carbon Intensity (Per Gallon)

$$CI_{gallon} = \frac{(E_{feedstock} + E_{facility} + E_{distribution}) \times AF_{ethanol}}{V_{gallons}}$$

Where:

- CI_{gallon} = Carbon intensity per gallon ($kgCO_2e$/gallon)
- $E_{feedstock}$ = Upstream feedstock emissions ($kgCO_2e$)
- $E_{facility}$ = Facility production emissions ($kgCO_2e$)
- $E_{distribution}$ = Distribution and transport emissions ($kgCO_2e$)
- $AF_{ethanol}$= Allocation factor for ethanol (dimensionless, 0-1)
- $V_{gallons}$ = Volume of ethanol produced (gallons)

5.2.2 Mass-Based Carbon Intensity (Per Kilogram / Per Token)

$$CI_{kg} = \frac{CI_{gallon}}{2.987\ kg/gallon} = \frac{(E_{feedstock}+E_{facility}+E_{distribution})\times AF_{ethanol}}{M_{kg}}$$

Where:

- CI_{kg}= Carbon intensity per kilogram ($kgCO_2e$/kg)
- M_{kg}= Mass of ethanol produced (kg) = $V_{gallons} \times 2.987$

This value represents the carbon intensity per QET-Ethanol token.

5.2.3 Energy-Based Carbon Intensity (For Regulatory Compliance)

$$CI_{MJ} = \frac{CI_{gallon}\times 1000}{80.53\ MJ/gallon}$$

Where:

- CI_{MJ} = Carbon intensity per megajoule (gCO_2e/MJ)
- Used for CARB LCFS, EPA RFS, and EU RED compliance reporting

5.2.4 Token Quantity Calculation

$$Tokens_{QET-Ethanol} = \left[V_{gallons} \times 2.987\ kg/gallon\right]$$

Where tokens are issued as whole kilogram units (fractional kg rounded down to the nearest kg per EarnDLT platform standards).

5.2.5 Standard Conversion Values

Metric	Value	Unit	Source/Reference
Ethanol density	0.789	kg/liter	ASTM D4806; CRC Handbook (anhydrous ethanol at 20°C)
Ethanol density	2.987	kg/gallon	Calculated: 0.789 kg/L × 3.78541 L/gal
Gallon to liter	3.78541	liters/gallon	NIST standard U.S. liquid gallon definition
Energy content (LHV)	76,330	BTU/gallon	U.S. DOE Alternative Fuels Data Center; CA-GREET 3.0
Energy content (LHV)	80.53	MJ/gallon	Calculated: 76,330 BTU × 1.05506 kJ/BTU ÷ 1000
Energy content (LHV)	21.27	MJ/liter	European Commission Eurostat; calculated: 80.53 MJ/gal ÷ 3.78541
Tokens per gallon	2.987	kg/gallon	EARN DLT mass-based QET standard (1 token = 1 kg)

Notes:

1. All energy values based on Lower Heating Value (LHV), which excludes latent heat of water vaporization, consistent with transportation fuel standards (ASTM D240, ISO 6976)
2. Density values for anhydrous ethanol (≥99% purity) at standard conditions (20°C/68°F, 1 atm)
3. Energy content values consistent with CARB LCFS, EPA RFS2, and EU RED II regulatory frameworks
4. Conversion factors from NIST (National Institute of Standards and Technology) standard reference data

5.3 Feedstock Emissions (E_feedstock)

Feedstock emissions encompass all activities from feedstock cultivation through delivery to the ethanol facility gate.

5.3.1 Sugar-Based Feedstock Emissions

For sugarcane, sugar beet, and sweet sorghum:

$$E_{feedstock,sugar} = E_{cultivation} + E_{harvest} + E_{transport}$$

Cultivation Emissions:

$$E_{cultivation} = (N_{fert} \times EF_{N2O,direct} + N_{fert} \times EF_{N2O,indirect}) \times GWP_{N2O} + (N_{fert} + P_{fert} + K_{fert}) \times EF_{fert,prod}$$

Where:

- N_{fert} = Nitrogen fertilizer application rate (kg N/hectare)
- $EF_{N2O,direct}$ = Direct N_2O emission factor (default 0.01 kg N_2O-N/kg N applied per IPCC)
- $EF_{N2O,indirect}$ = Indirect N_2O emission factor (default 0.0075 kg N_2O-N/kg N applied)
- GWP_{N2O} = Global warming potential of N_2O (265 for IPCC AR5, 298 for AR6)
- P_{fert}, K_{fert} = Phosphorus and potassium fertilizer rates
- $EF_{fert,prod}$ = Production emission factor for fertilizer manufacture

Harvest and Transport Emissions:

$$E_{harvest} = FC_{diesel} \times EF_{diesel}$$

$$E_{transport} = D_{transport} \times M_{feedstock} \times EF_{freight}$$

Where:

- FC_{diesel} = Diesel fuel consumption for harvest operations (liters)
- EF_{diesel} = Diesel emission factor (2.68 $kgCO_2e$/liter)
- $D_{transport}$ = Transportation distance (km)
- $M_{feedstock}$ = Mass of feedstock transported (metric tons)
- $EF_{freight}$ = Freight transport emission factor ($kgCO_2e$/ton-km)

Default Values (when facility-specific data is unavailable):

- Sugarcane cultivation: 450-850 $kgCO_2e$/ton fresh weight (region-dependent)
- Sugar beet cultivation: 380-620 $kgCO_2e$/ton fresh weight
- Transport (truck, 100 km average): 0.062 $kgCO_2e$/ton-km

5.3.2 Starch-Based Feedstock Emissions

For corn, wheat, grain sorghum, and other grains:

$$E_{feedstock,starch} = E_{cultivation} + E_{drying} + E_{transport} + E_{storage}$$

Cultivation Emissions (similar structure to sugar feedstocks):
Includes fertilizer production and application, pesticide production, diesel for field operations, N_2O emissions from soil, and irrigation energy (if applicable).

Grain Drying Emissions:

$$E_{drying} = \frac{M_{water,removed} \times H_{vap} \times \eta_{dryer}^{-1}}{LHV_{fuel}} \times EF_{fuel}$$

Where:

- $M_{water,removed}$ = Mass of water removed (kg)
- H_{vap} = Latent heat of vaporization (2.26 MJ/kg)
- η_{dryer} = Dryer thermal efficiency (typically 0.5-0.65)
- LHV_{fuel} = Heating value of drying fuel
- EF_{fuel} = Emission factor for drying fuel (natural gas or propane)

Default Values (when facility-specific data unavailable):

- Corn cultivation (US Midwest): 320-440 kgCO_2e/ton grain (15.5% moisture)
- Wheat cultivation: 280-380 kgCO_2e/ton grain
- Grain sorghum: 290-400 kgCO_2e/ton grain
- Grain drying (15% to 13% moisture): 25-35 kgCO_2e/ton grain
- Storage emissions: 5-10 kgCO_2e/ton-year

5.3.3 Cellulosic Feedstock Emissions

For agricultural residues, forestry residues, and energy crops:

$$E_{feedstock,cellulosic} = E_{collection} + E_{processing} + E_{transport} + E_{cultivation,energy}$$

Agricultural Residue Collection:
For corn stover, wheat straw, rice straw:

$$E_{collection} = (M_{residue} \times FC_{bale} \times EF_{diesel}) + (M_{residue} \times E_{nutrient,replacement})$$

Where:

- $M_{residue}$ = Mass of residue collected (dry metric tons)
- FC_{bale} = Fuel consumption for baling and collection (liters diesel/ton)
- $E_{nutrient,replacement}$ = Emissions from replacing removed nutrients (kgCO_2e/ton)

Nutrient Replacement: Residue removal depletes soil carbon and nutrients, requiring replacement fertilization. Default credit/debit: 50-100 $kgCO_2e$/ton residue removed.

Energy Crop Cultivation:
For switchgrass, miscanthus, and hybrid poplar:

- Include establishment year emissions (amortized over stand life)
- Annual harvest emissions
- Fertilizer inputs (typically lower than for annual crops)
- Carbon sequestration credit for perennial root systems (if documented)

Default Values:

- Corn stover collection: 40-60 $kgCO_2e$/dry ton
- Wheat straw collection: 35-55 $kgCO_2e$/dry ton
- Switchgrass production: 150-250 $kgCO_2e$/dry ton
- Miscanthus production: 120-200 $kgCO_2e$/dry ton
- Wood chips (forestry residue): 80-140 $kgCO_2e$/dry ton delivered

5.3.4 Synthetic Feedstock Emissions

For syngas-derived ethanol from industrial waste gases or gasification:

$$E_{feedstock,syngas} = E_{capture} + E_{conditioning} + E_{compression}$$

Where emissions depend on the source of syngas:

- **Steel mill off-gas:** Low emissions (waste gas capture and conditioning only)
- **Gasification of biomass:** Include biomass collection and gasification energy
- **Gasification of MSW:** Allocation methodology between waste management service and fuel production
- **Natural gas reforming:** Include natural gas extraction and reforming emissions

5.4 Facility Production Emissions (E_facility)

Facility emissions include all direct and indirect emissions from ethanol conversion processes.

5.4.1 Process Energy Emissions

$$E_{energy} = E_{thermal} + E_{electrical} + E_{other}$$

Thermal Energy Emissions:

$$E_{thermal} = \sum_{fuels} (Q_{fuel} \times LHV_{fuel} \times EF_{fuel,CO2} + Q_{fuel} \times EF_{fuel,CH4} \times GWP_{CH4} + Q_{fuel} \times EF_{fuel,N2O} \times GWP_{N2O})$$

Where:

- Q_{fuel} = Quantity of fuel consumed (volume or mass units)
- LHV_{fuel} = Lower heating value (MJ/unit)
- $EF_{fuel,GHG}$ = Emission factor for each greenhouse gas (kg/MJ or kg/unit)
- GWP = Global warming potential (CO_2=1, CH_4=28-30, N_2O=265-298)

Fuel-Specific Emission Factors:

- Natural gas: 56.1 $kgCO_2e$/mmBTU (EPA) or 53.06 $kgCO_2$/mmBTU + CH_4 + N_2O
- Coal: 95.3 $kgCO_2e$/mmBTU (bituminous) or 103.4 $kgCO_2e$/mmBTU (lignite)
- Fuel oil: 75.1 $kgCO_2e$/mmBTU (residual) or 73.2 $kgCO_2e$/mmBTU (distillate)
- Biomass (bagasse, lignin): 0 $kgCO_2e$/mmBTU for biogenic CO_2; include CH_4 and N_2O
- Biogas: 0 $kgCO_2e$/mmBTU for biogenic CO_2; include CH_4 and N_2O

Electrical Energy Emissions:

$$E_{electrical} = E_{purchased} \times EF_{grid} + E_{renewable} \times EF_{renewable}$$

Where:

- $E_{purchased}$ = Purchased electricity from grid (kWh)
- EF_{grid} = Grid emission factor ($kgCO_2e$/kWh, region-specific)
- $E_{renewable}$ = On-site renewable electricity generation (kWh)
- $EF_{renewable}$ = Emission factor for renewable generation (typically 0, include embodied emissions if material)

Grid Emission Factors (US Examples):

- ERCOT (Texas): 0.392 $kgCO_2e$/kWh
- Midwest (MROW): 0.744 $kgCO_2e$/kWh
- California: 0.233 $kgCO_2e$/kWh
- US Average: 0.386 $kgCO_2e$/kWh (EPA eGRID 2023)
- Use eGRID subregion factors for accuracy

5.4.2 Process Emissions

Fermentation CO_2:
Fermentation produces biogenic CO_2 according to stoichiometry:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

Theoretical yield: 1 kg glucose → 0.511 kg ethanol + 0.489 kg CO_2

Biogenic CO_2 from fermentation is **not counted** toward carbon intensity in most regulatory frameworks (LCFS, RFS, RED) as it is considered part of the biogenic carbon cycle. However, it must be **separately reported** for:

- Carbon capture and sequestration (CCS) credit quantification
- Transparency and full lifecycle documentation
- Potential future carbon capture requirements

$$CO_{2,fermintation} = V_{ethanol} \times \rho_{ethanol} \times \frac{44}{46} \times 0.97$$

Where:

- $\rho_{ethanol}$ = Density of ethanol (0.789 kg/L)
- 44/46 = Molecular weight ratio CO_2/ethanol
- 0.97 = Typical fermentation efficiency adjustment

Wastewater Treatment Emissions:
Aerobic and anaerobic treatment of stillage and process water generates CH_4 and N_2O:

$$E_{wastewater} = (COD_{removed} \times EF_{CH4,ww} \times GWP_{CH4}) + (N_{ww} \times EF_{N2O,ww} \times GWP_{N2O})$$

Where:

- $COD_{removed}$ = Chemical oxygen demand removed in treatment (kg)
- $EF_{CH4,ww}$ = CH_4 emission factor for wastewater (0.25 kg CH_4/kg COD for anaerobic)
- N_{ww} = Nitrogen in wastewater (kg)
- $EF_{N2O,ww}$ = N_2O emission factor (0.005-0.016 kg N_2O-N/kg N treated)

Default value: 0.5-2.0 kgCO_2e per gallon of ethanol produced (depends on treatment system)

Enzyme and Chemical Production:
Emissions from production of enzymes (amylase, cellulase), sulfuric acid, ammonia, and other process chemicals:

$$E_{chemicals} = \Sigma(M_{chemical,i} \times EF_{chemical,i})$$

Typical values:

- Enzymes: 2-5 $kgCO_2e$/kg enzyme
- Sulfuric acid: 0.15 $kgCO_2e$/kg
- Ammonia: 2.2 $kgCO_2e$/kg
- Lime (CaO): 1.1 $kgCO_2e$/kg

5.4.3 Fugitive Emissions

Ethanol storage and transfer operations result in evaporative losses:

$$E_{fugitive} = V_{loss} \times \rho_{ethanol} \times \frac{44}{46} \times GWP_{CO2}$$

Ethanol vapor is typically combusted (thermal oxidizer) or recovered (vapor recovery unit). If released, ethanol itself has negligible GWP but oxidizes to CO_2.

Typical ethanol loss rate: 0.2-0.5% of production volume

5.5 Co-Product Allocation

Ethanol production generates valuable co-products requiring emission allocation between outputs.

5.5.1 Allocation Methodologies

Three allocation approaches are recognized:

Energy Allocation Method (Default):
Allocate emissions based on energy content of products:

$$AF_{ethanol} = \frac{V_{ethanol} \times LVH_{ethanol}}{V_{ethanol} \times LVH_{ethanol} + \Sigma(M_{coproduct,i} \times LVH_{coproduct,i})}$$

Market Value Allocation Method:
Allocate emissions based on economic value:

$$AF_{ethanol} = \frac{V_{ethaol} \times P_{ethanol}}{V_{ethanol} \times P_{ethanol} + \Sigma(M_{coproduct,i} \times P_{coproduct,i})}$$

Displacement Method (System Expansion):
Credit ethanol production for displaced conventional products:

$$E_{net} = E_{total} - \Sigma(M_{coproduct,i} \times EF_{displaced,i})$$

Regulatory Alignment:

- LCFS and RFS use **energy allocation** as default
- RED II uses **energy allocation** as default
- ISCC allows multiple methods with documentation
- QET-Ethanol allows any method with transparent disclosure

5.5.2 Co-Product Energy Values

Corn Ethanol Co-Products:

- DDGS: 19.0 MJ/kg (dry basis)
- Wet distillers grains: 7.5 MJ/kg
- Corn oil: 37.5 MJ/kg

Sugarcane Ethanol Co-Products:

- Bagasse: 17.0 MJ/kg (dry basis)
- Vinasse (after biogas production): ~0 MJ/kg (waste disposal)
- Biogas from vinasse: 35.8 MJ/m³

Cellulosic Ethanol Co-Products:

- Lignin: 25.0 MJ/kg (dry basis)
- Biogas: 35.8 MJ/m³
- Electricity (if exported): 3.6 MJ/kWh

5.5.3 Allocation Example (Corn Ethanol)

Facility produces per batch:

- Ethanol: 100,000 gallons = 7,853 GJ
- DDGS: 270 tons (dry) = 5,130 GJ
- Total energy output: 12,983 GJ

$$AF_{ethanol} = \frac{7,853}{12,983} = 0.605$$

Therefore, 60.5% of facility emissions are allocated to ethanol, 39.5% to DDGS.

5.6 Distribution Emissions (E_distribution)

Transportation from ethanol facility to fuel terminal or blending facility (optional boundary):

$$E_{distribution} = D_{transport} \times V_{ethanol} \times \rho_{ethanol} \times EF_{freight,mode}$$

Transport Mode Emission Factors:

- Rail: 0.022 kgCO_2e/ton-km
- Barge: 0.031 kgCO_2e/ton-km
- Truck: 0.062 kgCO_2e/ton-km
- Pipeline: 0.0034 kgCO_2e/ton-km (ethanol pipelines are rare)

5.7 Credits and Avoided Emissions

5.7.1 Carbon Capture and Sequestration (CCS)

If fermentation CO_2 is captured and permanently sequestered:

$$Credit_{CCS} = M_{CO2,captured} \times \eta_{sequestration} \times (1 - LR)$$

Where:

- $M_{CO2,captured}$ = Mass of CO_2 captured and sequestered (kg)
- $\eta_{sequestration}$ = Sequestration efficiency (typically 0.95-0.99)
- LR = Leakage rate (default 0.01 for Class VI wells)

CCS credit must comply with EPA Class VI well requirements and monitoring protocols.

5.7.2 Renewable Energy Generation

On-site renewable electricity or thermal energy generation:

$$Credit_{renewable} = E_{renewable,surplus} \times EF_{grid,avoided}$$

Credit applies only to surplus renewable energy exported beyond facility needs, or to renewable energy used in place of fossil fuels.

5.7.3 Soil Carbon Sequestration

For energy crops with documented soil carbon accumulation:

$$Credit_{soil} = \Delta C_{soil} \times \frac{44}{12} \times A_{land} \times Y^{-1}$$

Where:

- ΔC_{soil} = Annual soil carbon accumulation rate (tons C/hectare-year)
- 44/12 = Molecular weight ratio CO_2/C
- A_{land} = Land area (hectares)
- Y = Crop yield (tons/year)

Soil carbon credits require field sampling and modeling per IPCC Tier 2 or 3 methods.

5.8 Pathway-Specific Calculation Examples

5.8.1 Corn Ethanol (Dry Mill, Natural Gas)

System Description:

- Feedstock: Corn grain (15.5% moisture)
- Process: Conventional dry mill with liquefaction, saccharification, fermentation
- Energy: Natural gas for process heat, grid electricity
- Co-products: DDGS (dried)
- Production Volume: 100,000 gallons/month

Physical Production Metrics:

- Volume: 100,000 gallons
- Mass: 100,000 gal × 2.987 kg/gal = 298,700 kg
- Energy content: 100,000 gal × 80.53 MJ/gal = 8,053,000 MJ
- QET-Ethanol tokens: 298,700 tokens (1 token = 1 kg)

Carbon Intensity Calculation:

Feedstock Emissions:

$$E_{feedstock} = 350\ kgCO_2e/ton\ corn \times 2.8\ ton/1000\ gal \times 100 = 98,000\ kgCO_2e$$

Facility Emissions:

$$E_{facility} = (30,000\ MJ\ NG \times 0.0561) + (1,200\ kWh \times 0.744) \times 100 = 257,000\ kgCO_2e$$

Total Emissions:

$$E_{total} = 98,000 + 257,600 = 355,600\ kgCO_2e$$

Energy Allocation:

$$AF_{ethanol} = 0.605$$

Allocated Emissions:

$$E_{allocated} = 355,600 \times 0.605 = 215,138\ kgCO_2e$$

Carbon Intensity - Per Gallon (Primary):

$$CI_{gallon} = \frac{215{,}138\ kgCO_2e}{100{,}000\ gallons} = 215\ kgCO_2e/gallon$$

Carbon Intensity - Per Kilogram (Per Token):

$$CI_{kg} = \frac{215{,}138\ kgCO_2e}{298{,}700\ kg} = 0.720\ kgCO_2e/kg = 720gCO_2e/kg$$

Carbon Intensity - Per MJ (Regulatory):

$$CI_{MJ} = \frac{2.15\ kgCO_2e/gal \times 1000}{80.53\ MJ/gal} = 26.7\ gCO_2e/MJ$$

Token Issuance and Platform Fees:

- QET-Ethanol tokens issued: 298,700 tokens
- Production fee: 298,700 kg × $0.0008 = $238.96
- Transfer fee: 298,700 kg × $0.0004 = $119.48 per transfer
- Total platform fees (production + 1 transfer): $358.44

Regulatory Comparison:

- CARB LCFS gasoline baseline: 95.86 gCO_2e/MJ
- This pathway: 26.7 gCO_2e/MJ
- Reduction: 72.1% from baselineEtahnol-Context.md

Summary:

Each QET-Ethanol token represents 1 kg of corn ethanol with a carbon intensity of 0.720 $kgCO_2e/kg$ (720 gCO_2e/kg). U.S. corn ethanol from conventional dry mill facilities with natural gas energy achieves moderate carbon intensity reductions compared to gasoline. The pathway demonstrates established commercial-scale production with energy allocation to dried distillers grains with solubles (DDGS) co-product, a valuable livestock feed supplement.

Pathway Advantages:

- Qualifies for D6 Renewable Fuel RIN under EPA RFS (most common RIN category)
- Generates LCFS credits in California for carbon reduction vs. baseline
- Well-established technology with proven verification protocols
- High co-product value (DDGS) enhances economic viability through energy allocation
- Can be upgraded to lower CI through process improvements (carbon capture, renewable energy substitution, improved efficiency)
- Represents baseline pathway for comparison with advanced biofuel technologies

5.8.2 Sugarcane Ethanol (Brazil, Bagasse Energy)

System Description:

- Feedstock: Sugarcane (whole cane with typical sucrose content 14-16%)
- Process: Juice extraction, fermentation, distillation, dehydration
- Energy: Bagasse combustion for process heat and electricity (surplus exported to grid)
- Co-products: Bagasse (after partial combustion for energy), vinasse (applied to fields)
- Production Volume: 75,000 gallons/month

Physical Production Metrics:

- Volume: 75,000 gallons
- Mass: 75,000 gal × 2.987 kg/gal = 224,025 kg
- Energy content: 75,000 gal × 80.53 MJ/gal = 6,039,750 MJ
- QET-Ethanol tokens: 224,025 tokens (1 token = 1 kg)

Carbon Intensity Calculation:

Feedstock Emissions:

$$E_{feedstock} = 650\ kgCO_2e/ton\ cane \times 10\ ton/1000\ gal \times 75 = 48,750\ kgCO_2e$$

Facility Emissions:

$$E_{facility} = (0\ MJ\ fossil\ fuel) + (500kWh\ grid \times 0.085) + 800\ chemicals = 843\ kgCO_2e$$

Note: Bagasse provides 100% of thermal energy; Brazil grid CI = 0.085 $kgCO_2e/kWh$

Total Emissions:

$$E_{total} = 48,750 + 843 = 49,593\ kgCO_2e$$

Energy Allocation:

Bagasse used for energy: 60% consumed internally, 40% generates surplus electricity exported

$$AF_{ethanol} = \frac{6,039,750\ MJ}{6,039,750+0} = 1.0$$ (no co-product with market value)

Vinasse returned to fields (no allocation), surplus electricity credited separately

$$E_{allocated} = 49,593 \times 1.0 = 49,593\ kgCO_2e$$

Renewable Energy Credit:

$$Credit_{surplus} = 25,000\ kWh\ surplus \times 0.085\ kgCO_2e/kWh = 2,125\ kgCO_2e$$

Net Emissions:

$$E_{net} = 49,593 - 2,125 = 47,468\ kgCO_2e$$

Carbon Intensity - Per Gallon (Primary):

$$CI_{gallon} = \frac{47,468\ kgCO_2e}{75,000\ gallons} = 0.633\ kgCO_2e/gallon$$

Carbon Intensity - Per Kilogram (Per Token):

$$CI_{kg} = \frac{47,468\ kgCO_2e}{224,025\ kg} = 0.212\ kgCO_2e/kg$$

Carbon Intensity - Per MJ (Regulatory):

$$CI_{MJ} = \frac{0.633\ kgCO_2e/gal \times 1000}{80.53\ MJ/gal} = 7.86\ gCO_2e/MJ$$

Token Issuance and Platform Fees:

- QET-Ethanol tokens issued: 224,025 tokens
- Production fee: 224,025 kg × $0.0008 = $179.22
- Transfer fee: 224,025 kg × $0.0004 = $89.61 per transfer
- Total platform fees (production + 1 transfer): $268.86

Regulatory Comparison:

- CARB LCFS gasoline baseline: 95.86 gCO_2e/MJ
- This pathway: 7.86 gCO_2e/MJ
- Reduction: 91.8% from baseline (highly advanced pathway)

Summary:

Each QET-Ethanol token represents 1 kg of Brazilian sugarcane ethanol with a carbon intensity of 0.212 $kgCO_2e/kg$ (212 gCO_2e/kg). Brazilian sugarcane ethanol achieves very low carbon intensity due to: (1) minimal fossil fuel use in cultivation (mechanical harvesting without burning), (2) bagasse-powered production facilities with surplus electricity generation, (3) efficient fermentation and distillation processes, and (4) vinasse recycling to fields as fertilizer.

Pathway Advantages:

- Qualifies for D5 Advanced Biofuel RIN under EPA RFS
- Generates substantial LCFS credits in California (>90% reduction)
- Meets EU RED II sustainability criteria with low ILUC risk certification
- Demonstrates integrated biorefinery with renewable energy co-generation
- Often eligible for additional carbon capture credits if fermentation CO_2 is captured

5.8.3 Cellulosic Ethanol (Corn Stover)

System Description:

- Feedstock: Corn stover (agricultural residue)
- Process: Thermochemical pretreatment, enzymatic hydrolysis, fermentation
- Energy: Lignin combustion for process heat, grid electricity
- Co-products: Lignin (after partial combustion), biogas from wastewater
- Production Volume: 50,000 gallons/month

Physical Production Metrics:

- Volume: 50,000 gallons
- Mass: 50,000 gal × 2.987 kg/gal = 149,350 kg
- Energy content: 50,000 gal × 80.53 MJ/gal = 4,026,500 MJ
- QET-Ethanol tokens: 149,350 tokens (1 token = 1 kg)

Carbon Intensity Calculation:

Feedstock Emissions:

$$E_{feedstock} = 50\ kgCO_2e/ton\ stover \times 3.5\ ton/1000\ gal \times 50 = 8,750\ kgCO_2e$$

Facility Emissions:

$$E_{facility} = (15,000\ MJ\ lignin \times 0) + (800\ kWh \times 0.744) + 200\ enzymes = 832\ kgCO_2e$$

Note: Lignin combustion is biogenic, thus 0 $kgCO_2e/MJ$ for CO_2

Total Emissions:

$$E_{total} = 8,750 + 832 = 9,582\ kgCO_2e$$

No Co-Product Allocation Required:

(Lignin fully consumed for energy, wastewater biogas captured)

$$E_{alloated} = 9,582\ kgCO_2e$$

Carbon Intensity - Per Gallon (Primary):

$$CI_{gallon} = \frac{9{,}582\ kgCO_2e}{50{,}000\ gallons} = 0.192 kgCO_2e/gallon$$

Carbon Intensity - Per Kilogram (Per Token):

$$CI_{kg} = \frac{9{,}582\ kgCO_2e}{149{,}350\ kg} = 0.0642\ kgCO_2e/kg$$

Carbon Intensity - Per MJ (Regulatory):

$$CI_{MJ} = \frac{0.192\ kgCO_2e/gal \times 1000}{80.53\ MJ/gal} = 2.38\ gCO_2e/MJ$$

Token Issuance and Platform Fees:

- QET-Ethanol tokens issued: 149,350 tokens
- Production fee: 149,350 kg × $0.0008 = $119.48
- Transfer fee: 149,350 kg × $0.0004 = $59.74 per transfer
- Total platform fees (production + 1 transfer): $179.22

Regulatory Comparison:

- CARB LCFS gasoline baseline: 95.86 gCO_2e/MJ
- This pathway: 2.38 gCO_2e/MJ
- Reduction: 97.5% from baseline (highly advanced pathway)

Summary:

Each QET-Ethanol token represents 1 kg of cellulosic ethanol with an ultra-low carbon intensity of 0.0642 $kgCO_2e/kg$ (64.2 gCO_2e/kg). This pathway achieves one of the lowest carbon intensities in commercial biofuel production due to: (1) low-emission feedstock collection from agricultural residue, (2) biogenic lignin energy source, and (3) minimal process emissions.

Pathway Advantages:

- Qualifies for D3 Cellulosic RIN under EPA RFS
- Generates significant LCFS credits in California (>93 gCO_2e/MJ reduction)
- Meets EU RED II advanced biofuel criteria
- Demonstrates circular agriculture waste valorization

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6. Uncertainty Reporting Requirements

6.1 Uncertainty Assessment Framework

Uncertainty assessment for QET-Ethanol follows ISO 14064-3 requirements and must address both **systematic uncertainty** (bias) and **random uncertainty** (precision). All significant emission sources must have documented uncertainty bounds expressed as 95% confidence intervals.

6.2 Uncertainty Quantification Methods

6.2.1 Approach 1: Statistical Analysis (Preferred)

For measured data with sufficient sample size:

$$U_{95} = 1.96 \times \frac{\sigma}{\sqrt{n}}$$

Where:

- σ = Standard deviation of measurements
- n = Number of independent measurements
- 1.96 = Z-score for 95% confidence interval

6.2.2 Approach 2: Propagation of Uncertainty

For calculated values combining multiple uncertain inputs:

$$U_{total} = \sqrt{\Sigma(U_i \times S_i)^2}$$

Where:

- U_i = Fractional uncertainty of input i
- S_i = Sensitivity coefficient (partial derivative)

6.2.3 Approach 3: Expert Judgment

When statistical data are unavailable, use conservative expert estimates documented with justification.

6.3 Source-Specific Uncertainty Targets

Emission Source	Target Uncertainty (±%)	Acceptable Uncertainty (±%)
Ethanol production volume	2%	5%
Feedstock quantity	3%	8%
Natural gas consumption	2%	5%
Electricity consumption	1%	3%
Co-product quantity	5%	10%
Fermentation CO_2 (biogenic)	10%	20%
Wastewater emissions	25%	50%
Transport distances	10%	20%
Emission factors (Tier 1)	5%	10%
Emission factors (Tier 2-3)	15%	30%

6.4 Overall Carbon Intensity Uncertainty

The combined uncertainty for carbon intensity must be calculated and reported:

$$U_{CI,total} = \sqrt{U^2_{feedstock} + U^2_{facility} + U^2_{allocation} + U^2_{measurement}}$$

Acceptable Thresholds:

- Target overall uncertainty: ±8%
- Maximum acceptable uncertainty: ±15%
- If uncertainty exceeds 15%, conservative adjustments must be applied

6.5 Conservative Adjustment Factor

When uncertainty exceeds target thresholds, apply conservative adjustment:

$$CI_{reported} = CI_{calculated} \times (1 + U_{excess} \times 0.5)$$

Where U_{excess} is the fractional uncertainty exceeding the 8% target.

6.6 Uncertainty Documentation Requirements

The QET Producer must document:

- Uncertainty quantification method for each source
- Data quality tier and associated uncertainty
- Sample sizes and statistical parameters
- Conservative assumptions applied
- Calibration records for measurement equipment
- Comparison with industry benchmarks
- Justification for any uncertainties exceeding acceptable levels

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7. QET-Ethanol Data Structure and Required Fields

7.1 Data Structure Overview

QET-Ethanol tokens are represented as digital assets with embedded metadata following JSON schema standards. The data structure extends the Core QET schema with ethanol-specific attributes.

7.2 Required Data Fields

7.2.1 Token Identification Fields

json

```json
{
  "tokenType": "QET-Ethanol",
  "tokenID": "QET-ETH-20251031-0001-ABCDEF",
  "version": "1.0",
  "issuanceDate": "2025-10-31T12:00:00Z",
  "reportingPeriod": {
    "startDate": "2025-10-01T00:00:00Z",
    "endDate": "2025-10-31T23:59:59Z"
  },
  "serialNumberRange": {
    "startSerial": "ETH-2025-10-000001",
    "endSerial": "ETH-2025-10-050000"
  }
}
```


7.2.2 Facility Information Fields

json


```json
{
  "facility": {
    "facilityID": "EPA-GHGRP-1234567",
    "facilityName": "Example Ethanol LLC",
    "operatorName": "Example Energy Corporation",
    "address": {
      "street": "123 Industrial Parkway",
      "city": "Cornville",
      "state": "IA",
      "postalCode": "50001",
      "country": "USA"
    },
    "coordinates": {
      "latitude": 42.0123,
      "longitude": -93.4567
    },
    "facilityType": "Dry Mill Corn Ethanol",
    "operationalStatus": "Active",
    "certifications": [
      "EPA-RFS-Producer-12345",
```

```
      "CARB-LCFS-Pathway-67890",
      "ISCC-EU-12345678"
    ],
    "productionCapacity": {
      "value": 100,
      "unit": "million gallons per year"
    }
  }
}
```

7.2.3 - PRODUCTION INFORMATION FIELDS (JSON)

json

```
{
  "production": {
    "volumetric": {
      "gallons": 100000,
      "liters": 378541,
      "specification": "anhydrous",
      "purity": 99.5,
      "conditions": "60°F, 1 atm",
      "measurementMethod": "Calibrated Coriolis flow meter with
temperature compensation"
    },
    "mass": {
      "totalKg": 298700,
      "calculationMethod": "Volume (gallons) × 2.987 kg/gallon",
      "density": 0.789,
      "densityUnit": "kg/liter",
      "densityConditions": "20°C, anhydrous"
    },
    "energy": {
      "totalMJ": 8053000,
      "LHV_perGallon": 80.53,
      "LHV_perKg": 26.97,
      "unit": "MJ"
    },
    "tokenQuantity": {
      "issued": 298700,
```

```
      "unit": "QET-Ethanol tokens",
      "basis": "1 token = 1 kg anhydrous ethanol",
      "conversionFactor": 2.987,
      "conversionUnit": "kg/gallon",
      "fractionalKg": 0,
      "note": "Tokens issued as whole kilogram units per EARN DLT
mass-based QET standards"
    },
    "productionProcess": "Biological fermentation with enzymatic
saccharification",
    "fermentationOrganism": "Saccharomyces cerevisiae"
  }
}
```


7.2.4 Feedstock Information Fields

json


```
{
  "feedstock": {
    "primaryFeedstock": {
      "type": "Corn grain",
      "classification": "First-generation starch",
      "quantity": {
        "value": 140,
        "unit": "metric tons"
      },
      "moisture": {
        "value": 15.5,
        "unit": "percent"
      },
      "origin": {
        "region": "Iowa, USA",
        "averageTransportDistance": {
          "value": 85,
          "unit": "km"
        },
        "sustainabilityCertification": "RSB-Advanced-Fuels-2025"
      },
```

```
      "cultivationEmissions": {
        "value": 350,
        "unit": "kgCO2e per metric ton",
        "methodology": "CA-GREET 3.0 Iowa corn default"
      }
    },
    "enzymes": [
      {
        "type": "Alpha-amylase",
        "quantity": {
          "value": 12,
          "unit": "kg"
        }
      },
      {
        "type": "Glucoamylase",
        "quantity": {
          "value": 8,
          "unit": "kg"
        }
      }
    ]
  }
}
```

7.2.5 Co-Product Information Fields

json

```
{
  "coProducts": [
    {
      "name": "Distillers Dried Grains with Solubles (DDGS)",
      "quantity": {
        "value": 42.5,
        "unit": "metric tons",
        "moisture": 10
      },
      "energyContent": {
```

```
        "total": 807,
        "unit": "GJ",
        "LHV": 19.0,
        "LHVUnit": "MJ/kg"
      },
      "disposition": "Sold as livestock feed",
      "allocationMethod": "Energy allocation",
      "allocationFactor": 0.395
    },
    {
      "name": "Corn oil",
      "quantity": {
        "value": 1.2,
        "unit": "metric tons"
      },
      "energyContent": {
        "total": 45,
        "unit": "GJ"
      },
      "disposition": "Sold for biodiesel production"
    }
  ]
}
```

7.2.6 - EMISSIONS DATA FIELDS (JSON)

json

```
{
  "emissions": {
    "carbonIntensity": {
      "perGallon": {
        "value": 2.15,
        "unit": "kgCO2e/gallon",
        "designation": "Primary functional unit metric"
      },
      "perKilogram": {
        "value": 0.720,
        "unit": "kgCO2e/kg",
        "designation": "Per token carbon intensity",
```

```
        "note": "Each QET-Ethanol token represents this carbon
footprint"
      },
      "perMegajoule": {
        "value": 26.7,
        "unit": "gCO2e/MJ",
        "designation": "Regulatory compliance metric (LCFS/RFS/RED)",
        "conversionMethod": "(kgCO2e/gal × 1000) / 80.53 MJ/gal"
      },
      "calculationMethod": "ISO 14044 lifecycle assessment with
energy-based co-product allocation per CARB LCFS methodology",
      "baselineComparison": {
        "baseline": "CARB LCFS gasoline baseline 2025",
        "baselineCI": 95.86,
        "baselineUnit": "gCO2e/MJ",
        "reductionPercentage": 72.1,
        "complianceStatus": "Qualifies for LCFS credit generation"
      }
    },
    "totalEmissions": {
      "gross": {
        "value": 355600,
        "unit": "kgCO2e",
        "scope1": 257600,
        "scope2": 0,
        "scope3": 98000
      },
      "allocated": {
        "value": 215138,
        "unit": "kgCO2e",
        "allocationFactor": 0.605,
        "allocationMethod": "Energy content basis"
      },
      "perGallon": {
        "value": 2.15,
        "unit": "kgCO2e/gallon"
      },
      "perKilogram": {
```

```
        "value": 0.720,
        "unit": "kgCO2e/kg"
      },
      "perToken": {
        "value": 0.720,
        "unit": "kgCO2e per QET-Ethanol token",
        "note": "1 token = 1 kg ethanol"
      }
    },
    "biogenicCO2": {
      "fermentation": {
        "value": 292400,
        "unit": "kgCO2",
        "counted": false,
        "note": "Biogenic carbon not counted per IPCC guidelines"
      }
    }
  }
}
```

7.2.7 Verification Information Fields

json

```
{
  "verification": {
    "verificationBody": "Green Verify LLC",
    "accreditation": "ANAB-ISO-14065-2024-0123",
    "leadVerifier": {
      "name": "Jane Smith, P.E.",
      "credentials": "ISO 14064-3 Lead Verifier, Professional
Engineer",
      "verifierID": "GV-2024-JS-001"
    },
    "verificationStandard": "ISO 14064-3:2019",
    "assuranceLevel": "Reasonable",
    "verificationDate": "2025-10-31",
    "verificationStatement":
"https://registry.qet.io/verification/statement-12345.pdf",
```

```
    "siteVisit": {
      "conducted": true,
      "date": "2025-10-15",
      "duration": "2 days"
    },
    "materialMisstatement": {
      "identified": false,
      "description": "None"
    },
    "verificationOpinion": "The GHG assertion is free from material
misstatement and conforms to ISO 14064-3.",
    "uncertaintyAssessment": {
      "overallUncertainty": 8.5,
      "unit": "percent",
      "acceptableThreshold": 15
    }
  }
}
```

7.2.8 Platform Fees and Registry Information Fields

json

```
{
  "platformIntegration": {
    "platform": "EARN DLT",
    "qetClassification": "Mass-Based QET",
    "unitOfMeasure": "kilogram (kg)",
    "pricingVersion": "v2.0",
    "effectiveDate": "2025-09-01",
    "registryURL": "https://registry.earndlt.com"
  },
  "networkInfrastructureFees": {
    "feeStructure": "Mass-based QET per EARN DLT Platform Pricing
Structure v2",
    "productionFee": {
      "rate": 0.0008,
      "unit": "USD per kg",
      "totalTokens": 298700,
```

      "totalFee": 238.96,
      "calculation": "298,700 kg × $0.0008",
      "feePerGallon": 0.002389,
      "rationale": "Mid-range commodity with standardized mass measurements per EARN DLT pricing structure"
    },
    "transferFee": {
      "rate": 0.0004,
      "unit": "USD per kg",
      "appliedPer": "transfer transaction",
      "feePerTransfer": 119.48,
      "feePerGallon": 0.001195
    },
    "totalPlatformCost": {
      "productionOnly": 238.96,
      "withTwoTransfers": 477.92,
      "perGallonTotal": 0.004779,
      "percentOfProductValue": 0.19,
      "assumedEthanolPrice": 2.50,
      "note": "Assuming $2.50/gallon ethanol market price"
    },
    "revenueSharing": {
      "model": "Tier-based revenue sharing",
      "tiers": {
        "entry": {
          "monthlyRevenue": "0-500000",
          "producerShare": 0.60,
          "earnDLTShare": 0.40
        },
        "growth": {
          "monthlyRevenue": "500001-2000000",
          "producerShare": 0.65,
          "earnDLTShare": 0.35
        },
        "professional": {
          "monthlyRevenue": "2000001-5000000",
          "producerShare": 0.68,
          "earnDLTShare": 0.32

```
        },
        "enterprise": {
          "monthlyRevenue": "5000001+",
          "producerShare": 0.70,
          "earnDLTShare": 0.30
        }
      },
      "marketplaceClearingFee": {
        "rate": 0.001,
        "description": "0.1% of transaction value for Greentruth marketplace sales"
      }
    },
    "serviceOptions": {
      "standardTier": {
        "cost": 0,
        "marketplaceRequired": true,
        "description": "No monthly subscription, mandatory Greentruth marketplace listing"
      },
      "earnPremium": {
        "cost": 5000,
        "costUnit": "USD per month",
        "marketplaceRequired": false,
        "features": [
          "Direct bilateral transactions",
          "Custom pricing negotiations",
          "Private transaction capabilities",
          "Growth-tier minimum guarantee (65%+)",
          "Enhanced settlement control"
        ]
      }
    }
  }
}
```

7.2.9 Compliance and Registry Fields

json

```json
{
  "compliance": {
    "applicablePrograms": [
      {
        "program": "California LCFS",
        "pathwayCode": "CA-123456",
        "certifiedCI": 28.2,
        "certificationDate": "2025-05-15",
        "expirationDate": "2030-05-15"
      },
      {
        "program": "Federal RFS",
        "RIN": "D6",
        "generationYear": 2025,
        "equivalenceValue": 1.0
      }
    ],
    "sustainabilityCertifications": [
      {
        "scheme": "RSB Advanced Fuels",
        "certificateNumber": "RSB-AF-2025-12345",
        "validity": "2025-01-01 to 2025-12-31"
      }
    ],
    "registry": {
      "registryName": "EarnDLT Registry",
      "registryURL": "https://registry.earndlt.com",
      "retirementStatus": "Active",
      "ownerAccount": "0x1234567890abcdef",
      "blockchain": {
        "network": "EarnDLT",
        "contractAddress": "0xabcdef1234567890",
        "tokenStandard": "ERC-1155",
        "transactionHash": "0x9876543210fedcba"
      }
    }
  }
}
```

7.3 Complete JSON Schema Example

A complete QET-Ethanol token with all required fields is provided in Appendix A.

---

8. Verification and Validation Requirements

8.1 Verification Principles

Verification of QET-Ethanol production shall be conducted in accordance with ISO 14064-3:2019 and ISO 14065:2020. The verification process provides independent assurance that:

- GHG quantification is materially correct
- Quantification methods conform to this methodology
- Data quality meets specified requirements
- Supporting documentation is complete and traceable
- Internal controls are adequate
- No material misstatements exist in the GHG assertion

8.2 Verification Types

8.2.1 Reasonable Assurance (Default)

Provides high but not absolute level of assurance through comprehensive testing and evidence gathering. Verification opinion states whether GHG assertion is free from material misstatement.

8.2.2 Limited Assurance

Provides moderate level of assurance through limited procedures. May be acceptable for initial verification periods or low-materiality applications. Opinion states whether anything came to verifier's attention indicating material misstatement.

Materiality Threshold: Misstatements exceeding 5% of total emissions or carbon intensity are considered material for reasonable assurance.

8.3 Verification Scope

The verification shall encompass:

8.3.1 Organizational Boundaries

- Confirmation of facility ownership and operational control
- Review of organizational structure and reporting relationships
- Identification of all emission sources under facility control

8.3.2 Operational Boundaries

- Verification that all material emission sources are included
- Assessment of boundary completeness
- Review of Scope 1, 2, and 3 emission categorization

8.3.3 Quantification Methods

- Review of calculation methodologies for conformance with this document
- Assessment of emission factor selection and applicability
- Evaluation of allocation methodologies
- Review of uncertainty quantification

8.3.4 Data Management

- Assessment of data collection and management systems
- Evaluation of internal controls and quality assurance procedures
- Testing of data accuracy through sampling and recalculation
- Review of calibration and maintenance records

8.3.5 Supporting Documentation

- Production records and quality control data
- Feedstock procurement and chain of custody documentation
- Energy consumption records and utility bills
- Co-product sales records and disposition evidence
- Regulatory reporting submissions (EPA GHGRP, state programs)
- Previous verification reports and corrective actions

8.4 Verification Planning

8.4.1 Pre-Verification Activities

The verification body shall:

- Review previous verification reports and findings
- Conduct risk assessment to identify areas of high uncertainty or error risk
- Develop sampling plan based on materiality and risk

- Identify specific verification criteria and evidence requirements
- Communicate verification plan to QET Producer

8.4.2 Strategic Analysis

Assessment of:

- Production process complexity
- Data management system capabilities
- Personnel competence and training
- Changes from previous reporting periods
- External data dependencies (supplier data, emission factors)

8.4.3 Risk Assessment

Identify risks of material misstatement from:

- Measurement errors or equipment malfunctions
- Incomplete data capture
- Inappropriate methodologies
- Calculation errors
- Misapplication of allocation methods
- Fraudulent reporting

8.5 Evidence Gathering

8.5.1 Document Review

Examination of:

- GHG Management Plan and Standard Operating Procedures
- Data collection forms and databases
- Calculation spreadsheets and models
- QA/QC records and corrective action logs
- Training records for personnel
- Contracts with suppliers and co-product purchasers

8.5.2 Interviews

Discussions with:

- Facility management
- Environmental/sustainability staff

- Operations personnel
- Laboratory technicians
- Maintenance personnel

- Third-party data providers

8.5.3 Data Testing

Statistical sampling and recalculation of:

- Ethanol production volumes (minimum 10% of reporting period)
- Energy consumption data (minimum 25% of significant sources)
- Feedstock quantities (minimum 15% of deliveries)
- Emission calculations (100% of methodologies)
- Co-product allocations (100% verification)

8.5.4 Observation and Inspection

Physical verification of:

- Metering and monitoring equipment
- Calibration tags and certifications
- Process equipment and emission sources
- Storage and handling facilities
- Control room instrumentation

8.5.5 External Confirmations

Independent verification from:

- Utility companies (energy consumption)
- Feedstock suppliers (delivery quantities)
- Co-product purchasers (offtake quantities)
- Laboratories (analytical results)
- Regulatory agencies (compliance status)

8.6 Findings and Reporting

8.6.1 Classification of Findings

Conformance: GHG assertion conforms to the methodology without material misstatement.

Non-conformance (Major): Material misstatement identified requiring correction before verification can be completed. Examples:

- Emissions underreported by >5%
- Inappropriate methodology applied
- Inadequate documentation for significant emission sources
- System boundary errors resulting in material omissions
- Failure to apply required allocation methods

Non-conformance (Minor): Issues that do not result in a material misstatement but require corrective action. Examples:

- Documentation gaps for immaterial sources
- Clerical errors in calculations that do not affect final CI
- QA/QC procedure deficiencies
- Calibration records incomplete but equipment verified accurate

Opportunity for Improvement: Recommendations for enhanced data quality or process efficiency without requiring corrective action.

8.6.2 Corrective Action Process

For all non-conformances, the QET Producer must:

- Acknowledge the finding
- Investigate root cause
- Implement corrective action
- Provide evidence of correction to verifier
- Update documentation and procedures to prevent recurrence

Timeline for corrective actions:

- Major non-conformances: Must be resolved before verification opinion issued
- Minor non-conformances: Must be resolved within 30 days of verification report
- Opportunities for improvement: No mandatory timeline

8.6.3 Verification Statement

The verification body shall issue a written verification statement containing:

- Verification scope and objectives
- Identification of QET Producer and facility
- Description of GHG assertion being verified
- Verification standard and criteria applied
- Level of assurance (reasonable or limited)
- Summary of verification activities performed
- Materiality threshold applied
- Overall uncertainty assessment
- Description of any material misstatements identified

- Verification opinion (positive, qualified, or adverse)
- Limitations or exclusions
- Name and credentials of lead verifier

- Date and signature

Verification Opinion Language:

Positive Opinion (Reasonable Assurance):
"Based on our verification activities, in our professional judgment, the GHG assertion for [Facility Name] for the reporting period [dates] is free from material misstatement and conforms to the Methodology for the Production and Verification of Ethanol Quantified Emissions Tokens in accordance with ISO 14064-3:2019."

Qualified Opinion:
"Based on our verification activities, except for [describe issue], the GHG assertion is free from material misstatement..."

Adverse Opinion:
"Based on our verification activities, the GHG assertion contains material misstatements and does not conform to the applicable methodology."

8.7 Verification Cycle and Frequency

8.7.1 Initial Verification

The first verification for a facility shall include:

- Complete assessment of organizational and operational boundaries
- Comprehensive review of all data management systems
- Full evaluation of quantification methodologies
- On-site inspection of all significant emission sources
- Detailed assessment of internal controls
- Training needs assessment for facility personnel

8.7.2 Annual Verification (Standard)

Subsequent verifications shall be conducted annually and include:

- Review of any changes to boundaries, processes, or methodologies
- Sampling-based data testing
- On-site visit (may be reduced scope if strong controls demonstrated)
- Review of previous corrective actions
- Updated risk assessment

8.7.3 Interim Verification (Optional)

Quarterly or semi-annual verification may be conducted for:

- High-volume producers requiring more frequent QET issuance
- Facilities with significant process variability
- Initial operating periods to establish data quality
- Regulatory compliance requirements

8.8 Special Verification Considerations for Ethanol

8.8.1 Feedstock Sustainability Verification

When sustainability certifications are claimed (RSB, ISCC, Bonsucro), the verifier must:

- Confirm validity of certification
- Review chain of custody documentation
- Verify mass balance calculations for mixed feedstocks
- Assess compliance with sustainability criteria
- Confirm traceability to certified origins

8.8.2 Co-Product Allocation Verification

The verifier must:

- Verify accuracy of co-product quantities and energy contents
- Confirm appropriateness of allocation methodology
- Recalculate allocation factors independently
- Review co-product disposition evidence (sales records, contracts)
- Assess consistency with regulatory requirements when applicableEtahnol-Context.md+1

8.8.3 Biogenic Carbon Accounting

The verifier must:

- Confirm fermentation CO_2 is calculated but not counted toward CI
- Verify proper treatment of biomass combustion emissions
- Review carbon neutrality assumptions for feedstock growth
- Assess land use change emissions when applicable
- Confirm consistency with IPCC guidelines

8.8.4 CCS Credit Verification

When carbon capture credits are claimed, additional verification required:

- EPA Class VI well injection verification
- CO_2 purity and quantity measurement verification
- Monitoring, reporting, and verification (MRV) plan review
- Long-term storage assurance assessment
- Leakage risk evaluation
- Additionality demonstration

---

9. Reporting and Communication

9.1 GHG Assertion Requirements

The QET Producer shall prepare a written GHG assertion for each reporting period that includes:

9.1.1 Executive Summary

- Facility identification and description
- Reporting period
- Total ethanol production volume
- Total GHG emissions (gross and allocated)
- Carbon intensity (gCO_2e/MJ)
- Comparison to previous periods or baselines
- Summary of significant changes

9.1.2 Organizational Boundaries

- Legal entity structure
- Operational control documentation
- Ownership percentages for joint ventures
- Changes from previous periods

9.1.3 Operational Boundaries

- Complete listing of emission sources
- Categorization by Scope 1, 2, and 3
- Justification for any exclusions
- Emission source diagrams

9.1.4 Quantification Methodology

- Detailed description of calculation methods
- Emission factors used with sources

- Tier levels for each emission source
- Allocation methodologies applied
- Uncertainty quantification approach

9.1.5 Activity Data

- Ethanol production volumes by month
- Feedstock consumption by type and source
- Energy consumption by fuel type
- Co-product generation by type
- Process operational parameters

9.1.6 Emission Calculations

- Detailed calculations for each emission source
- Aggregation by category (feedstock, facility, distribution)
- GHG breakdown by species (CO_2, CH_4, N_2O)
- Allocation calculations
- Carbon intensity determination

9.1.7 Quality Assurance

- Data quality assessment
- Uncertainty analysis
- Calibration and maintenance records
- Internal QC review results
- Comparison with benchmarks

9.1.8 Supporting Documentation

- Feedstock certificates and chain of custody
- Energy bills and meter readings
- Laboratory analytical results
- Co-product sales records
- Regulatory compliance documentation
- Previous verification reports

9.2 Public Disclosure Requirements

The following information shall be publicly disclosed for each QET-Ethanol issuance:

Mandatory Public Information:

- Facility name and location (city, state, country)
- Reporting period
- Production volume (gallons and kilograms)
- Number of QET-Ethanol tokens issued
- Carbon intensity:
  - Primary: $kgCO_2e$ per gallon
  - Per token: $kgCO_2e$ per kg
  - Regulatory: gCO_2e per MJ (if applicable)
- Feedstock type(s) used
- Co-product allocation method
- Verification body name
- Verification date and opinion
- QET classification: Mass-Based QET per EARN DLT platform
- Token-to-volume conversion factor (kg/gallon)
- Platform fees structure and rates

Token-Specific Disclosure:

- Total tokens: [X] QET-Ethanol tokens
- Mass representation: [X] kilograms
- Volume representation: [X] gallons
- Carbon footprint per token: [X] $kgCO_2e/kg$
- Platform production fee paid: $[X]
- Registry: EARN DLT Mass-Based QET Registry

Tokenization Methodology:

- Rounding method: Floor function (fractional kg rounded down)
- Rationale: Conservative approach ensures tokens only represent fully verified kilogram units
- Example: 298,668.8 kg → 298,668 tokens (not 298,669)
- Fractional kg disclosure: [X.XX] kg unrepresented (available for next issuance)

Confidential Business Information (CBI):

The following may be designated as CBI and withheld from public disclosure:

- Precise production volumes beyond order of magnitude
- Specific feedstock suppliers and contract terms

- Detailed process parameters and efficiencies
- Proprietary technology descriptions
- Exact emission source magnitudes
- Financial information

However, all CBI must be available to verifiers and regulatory authorities.

9.3 Registry Reporting Requirements

Upon successful verification, the QET Producer shall submit to the QET Registry:

- Complete QET data structure in JSON format
- Verification statement (PDF)
- GHG assertion document (PDF)
- Facility registration information
- Token generation request specifying quantity
- Attestation of data accuracy signed by responsible party
- Payment of applicable registry fees

The Registry shall:

- Validate data structure compliance
- Confirm verification statement authenticity
- Assign unique token identifiers
- Record tokens in blockchain ledger
- Publish public disclosure information
- Issue tokens to Producer's registry account

9.4 Communication and Claims

9.4.1 Permissible Claims

Holders of QET-Ethanol tokens may make the following claims:

- "Ethanol produced with verified carbon intensity of [X] kgCO_2e/gallon per ISO 14064-3"
- "Each QET-Ethanol token represents 1 kg of ethanol with verified emissions of [X] kgCO_2e/kg"
- "Carbon intensity verified by [Verification Body] on [Date]"
- "Mass-based QET registered on EARN DLT platform"
- "Represents [X] kilograms ([Y] gallons) of ethanol with third-party verified emissions data"
- "Meets [Regulatory Program] standards with [X]% carbon reduction vs. baseline"
- "Token-to-volume ratio: 2.987 kg/gallon (standardized)"

9.4.2 Prohibited Claims

The following claims are prohibited unless specifically substantiated:

- "Carbon neutral" or "net-zero" (unless CI ≤ 0)
- "Renewable" without specifying feedstock classification and certification
- "Sustainable" without third-party sustainability certification (RSB, ISCC)
- "Lowest emissions" without comparative data and market analysis
- Environmental benefit claims beyond GHG emissions without separate verification

9.4.3 Token Value Representation

When representing token value:

- Always specify: "1 QET-Ethanol token = 1 kg ethanol"
- Include volumetric equivalent when relevant: "1 gallon = ~2.987 tokens"
- State carbon intensity: "Each token carries [X] kgCO_2e/kg verified emissions"
- Reference platform: "Registered on EarnDLT Mass-Based QET platform"
- Disclose fees: "Platform infrastructure fees: $0.0008/kg production, $0.0004/kg transfer"

9.4.4 Marketing and Promotional Use

Organizations using QET-Ethanol for marketing purposes must:

- Maintain traceability between claims and retired tokens
- Avoid double-counting of environmental attributes
- Provide context for carbon intensity values
- Disclose verification standard and body
- Update claims if tokens are transferred or retired

---

10. Competence Requirements for Validators and Verifiers

10.1 Verification Body Requirements

Verification bodies conducting QET-Ethanol verification must:

10.1.1 Accreditation

Hold valid accreditation to ISO 14065:2020 and ISO/IEC 17029:2019 from a recognized accreditation body such as:

- ANAB (ANSI National Accreditation Board) - United States
- UKAS (United Kingdom Accreditation Service) - United Kingdom
- DAkkS (Deutsche Akkreditierungsstelle) - Germany
- INMETRO - Brazil
- Other IAF multilateral agreement signatories

Accreditation scope must explicitly include:

- Greenhouse gas verification per ISO 14064-3
- Biofuels sector or renewable energy sector
- Lifecycle assessment verification
- Optional: Specific regulatory programs (CARB, EPA, RED)

10.1.2 Independence and Impartiality

The verification body must:

- Be legally and operationally independent from the QET Producer
- Have no financial interest in the outcome of verification
- Implement conflict of interest policies
- Not provide consulting services to the same client within 2 years
- Rotate lead verifiers every 3 years for the same facility

10.1.3 Quality Management System

Maintain a quality management system including:

- Document control procedures
- Verification planning and execution protocols
- Technical review requirements
- Corrective action processes
- Internal audit program
- Management review procedures
- Continuous improvement mechanisms

10.2 Lead Verifier Competence Requirements

Lead verifiers for QET-Ethanol must demonstrate:

10.2.1 Education

Minimum bachelor's degree in:

- Chemical engineering
- Environmental engineering

- Chemistry
- Environmental science
- Agricultural engineering
- Or equivalent technical field

Advanced degrees (M.S., Ph.D.) preferred for complex cellulosic pathways.

10.2.2 GHG Verification Training

Completion of formal training in:

- ISO 14064-3 verification standard
- ISO 14065 accreditation requirements
- GHG quantification methodologies
- Lifecycle assessment (ISO 14040/14044/14067)
- Uncertainty assessment techniques
- Auditing and sampling methods

Minimum 40 hours of formal training with examination.

10.2.3 Ethanol Industry Experience

Demonstrated experience including:

- Minimum 3 years of professional experience in ethanol production, biofuels sector, or related field
- At least 5 GHG verifications as team member (any sector)
- At least 2 biofuel or ethanol verifications
- Knowledge of fermentation processes, distillation, and co-product systems
- Understanding of agricultural feedstock systems

10.2.4 Technical Knowledge Areas

Proficiency in:

- Ethanol production technologies (fermentation, distillation, dehydration)
- Feedstock characteristics and emissions (sugar, starch, cellulosic)
- Energy systems in ethanol facilities (boilers, CHP, biomass combustion)
- Co-product allocation methodologies
- Wastewater treatment systems
- Mass and energy balance calculations
- Process flow diagrams
- Agricultural emissions (fertilizer, N_2O, soil carbon)
- Transportation fuel regulations (LCFS, RFS, RED)

10.2.5 Regulatory Knowledge

Understanding of:

- EPA Renewable Fuel Standard (RFS2) - 40 CFR Part 80
- CARB Low Carbon Fuel Standard (if verifying LCFS compliance)
- EU Renewable Energy Directive (if verifying EU exports)
- EPA GHG Reporting Program (40 CFR Part 98, Subpart MM)
- Sustainability certification schemes (RSB, ISCC, Bonsucro)
- Carbon capture and sequestration regulations (if applicable)

10.2.6 Ongoing Professional Development

Annual completion of:

- Minimum 20 hours of continuing education
- Updates on methodology changes
- Regulatory developments
- Technology advancements
- Participation in professional organizations (e.g., GHGMI, IETA)

10.3 Verification Team Composition

The verification team must include:

10.3.1 Lead Verifier

Meeting all requirements in Section 10.2, responsible for:

- Overall verification planning and execution
- Team coordination
- Risk assessment
- Stakeholder communication
- Verification opinion and statement
- Final report approval

10.3.2 Technical Specialists

As needed based on complexity:

- Agricultural specialist (for feedstock cultivation emissions)
- Process engineer (for complex or novel processes)
- Energy specialist (for CHP systems or renewable energy)
- LCA specialist (for comprehensive lifecycle modeling)

- Regulatory specialist (for LCFS or RED compliance)
- CCS specialist (if carbon capture is included)

10.3.3 Technical Reviewer

Independent review of verification findings by qualified personnel not involved in verification activities. Technical reviewer must have equal or greater qualifications than lead verifier.

10.4 Maintenance of Competence

Verification bodies shall:

- Conduct annual competence assessments for all verifiers
- Provide ongoing training for methodology updates
- Monitor verifier performance through internal audits
- Maintain records of education, training, and experience
- Participate in accreditation body witness assessments
- Implement remedial training when deficiencies identified

---

11. Independent Review Process

11.1 Purpose of Independent Review

The independent review process provides additional quality assurance by subjecting verification findings to review by qualified technical personnel not involved in the verification engagement. Independent review is mandatory for:

- All initial verifications of new facilities
- Verifications with qualified or adverse opinions
- Verifications where material misstatements were identified
- High-volume facilities (>50 million gallons/year)
- Novel or complex production pathways
- Facilities claiming CCS credits
- Any verification at discretion of verification body

11.2 Independent Reviewer Qualifications

The independent reviewer must:

- Meet or exceed lead verifier competence requirements

- Not have participated in the verification engagement
- Not have provided consulting services to the facility within 3 years
- Have no financial interest in verification outcome
- Be employed by verification body or qualified external expert

11.3 Review Scope

The independent review shall assess:

11.3.1 Verification Planning

- Adequacy of risk assessment
- Appropriateness of materiality threshold
- Sampling plan design
- Resource allocation and team competence

11.3.2 Evidence Evaluation

- Sufficiency of evidence gathered
- Appropriateness of evidence types
- Adequacy of testing procedures
- Documentation quality

11.3.3 Technical Findings

- Accuracy of calculations reviewed
- Appropriateness of methodologies applied
- Proper classification of conformances and non-conformances
- Reasonableness of professional judgments

11.3.4 Verification Opinion

- Consistency with evidence
- Appropriate qualification of limitations
- Clear communication of findings
- Compliance with ISO 14064-3 requirements

11.4 Review Process

Step 1: Documentation Review
Reviewer examines complete verification file including:

- Verification plan

- Working papers and evidence
- Calculation spreadsheets
- Interview notes
- Site visit observations
- Draft verification statement

Step 2: Assessment and Questioning
Reviewer prepares written questions and comments on:

- Areas requiring additional evidence
- Technical disagreements
- Alternative interpretations
- Missing documentation

Step 3: Resolution
Lead verifier responds to reviewer comments and:

- Provides additional evidence or explanation
- Conducts supplemental verification activities if needed
- Revises findings or opinion if warranted
- Documents resolution of all review comments

Step 4: Review Approval
Independent reviewer approves verification findings or escalates unresolved issues to verification body management.

11.5 Review Documentation

The following must be documented:

- Independent reviewer qualifications and conflict of interest statement
- Review checklist or protocol
- Reviewer comments and questions
- Lead verifier responses
- Resolution of discrepancies

- Reviewer approval signature and date
- Any unresolved issues and their disposition

All review documentation retained for 7 years with verification file.

---

12. Site Visit Requirements

12.1 Mandatory Site Visit Conditions

Physical site visits to the ethanol production facility are mandatory for:

- Initial verification of a new facility
- First verification under this methodology
- Annual verification unless waived (see Section 12.4)
- Verifications with material changes to processes or boundaries
- When remote verification limitations prevent adequate evidence gathering
- When risk assessment indicates high uncertainty or control weaknesses

12.2 Site Visit Objectives

Site visits shall accomplish the following objectives:

12.2.1 Physical Observation

- Verify existence and operation of emission sources
- Observe production processes and equipment
- Inspect metering and monitoring equipment
- Observe safety and environmental controls
- Assess facility layout against process diagrams

12.2.2 Personnel Interviews

- Facility management
- Environmental/sustainability staff
- Operations and maintenance personnel
- Laboratory technicians
- Data management staff

12.2.3 Document Review

- Original source records (not just summarized data)
- Calibration certificates
- Maintenance logs
- Laboratory notebooks
- Operational logbooks
- Regulatory compliance records

12.2.4 Data Validation

- Observe data collection procedures
- Review data entry and storage systems

- Test calculations independently
- Trace data from source through to GHG assertion
- Assess internal controls

12.3 Site Visit Duration and Scope

12.3.1 Initial Verification Site Visit

Minimum duration: 2-3 days depending on facility complexity

Activities:

- Complete facility tour of all emission sources
- Detailed review of data management systems
- Extensive personnel interviews
- Comprehensive document review
- Testing of all significant emission source calculations
- Assessment of internal control environment

12.3.2 Annual Surveillance Site Visit

Minimum duration: 1-2 days

Activities:

- Targeted facility tour focusing on changes
- Sample-based document review
- Key personnel interviews
- Risk-based testing of emission calculations
- Review of previous corrective actions
- Assessment of ongoing data quality

12.3.3 Expanded Scope Site Visit

Additional time required for:

- Multiple production lines or facilities
- Complex co-product systems
- On-site renewable energy generation
- Carbon capture systems
- Advanced or novel production technologies

12.4 Remote Verification Provisions

Remote verification (without physical site visit) may be permitted for annual surveillance verifications when:

Eligibility Criteria:

- At least one complete site visit conducted in previous 3 years
- No material changes to processes, boundaries, or data systems
- Strong internal controls demonstrated in previous verifications
- No significant non-conformances in previous verification
- Facility has remote access capabilities for document review
- Video conferencing available for interviews and virtual observation
- Risk assessment indicates low risk of material misstatement

Remote Verification Requirements:

- Virtual facility walkthrough via video
- Real-time observation of metering and monitoring equipment
- Screen-sharing for data system review
- Video interviews with key personnel
- Secure electronic access to source documents
- Enhanced sampling of documentary evidence (>25% vs. 10% for site visits)

Remote Verification Limitations:

- Cannot substitute for initial verification site visit
- Must alternate with physical site visits (maximum 2 consecutive remote verifications)
- Not permitted if material changes occurred
- Not permitted if CCS or complex renewable energy systems involved
- Verification body must document justification for remote approach

12.5 Site Visit Documentation

Site visit reports shall include:

- Date, duration, and participants
- Facility tour observations with photographs
- Equipment inspected (metering, monitoring, process equipment)
- Personnel interviewed and topics discussed
- Documents reviewed on-site
- Findings and observations
- Issues requiring follow-up
- Confirmation of site visit completion signed by facility representative

All site visit documentation retained in verification file.

13. Facts Discovered After Verification

13.1 Reporting Obligations

If facts are discovered after verification statement issuance that would have materially affected the verification opinion, the following parties have reporting obligations:

13.1.1 QET Producer Obligations

The QET Producer must notify the verification body and QET Registry within 30 days if they discover:

- Calculation errors affecting CI by >2%
- Omitted emission sources that are material (>5% of total)
- Incorrect data values or emission factors used
- Methodology misapplications
- Material misrepresentations in documentation
- Equipment calibration failures affecting reported emissions
- Changes to feedstock sustainability certifications

13.1.2 Verification Body Obligations

The verification body must notify the QET Producer and Registry within 30 days if they discover:

- Verification errors or oversights
- Evidence that was incomplete or inaccurate
- Changes to emission factors or methodology requirements
- Material facts not disclosed during verification

- Accreditation body findings affecting verification validity

13.1.3 Registry Obligations

The QET Registry must notify token holders and the public if material facts are discovered affecting token validity.

13.2 Investigation Process

Upon discovery of potential material facts:

Step 1: Preliminary Assessment (5 days)
Verification body conducts preliminary assessment to determine if issue is potentially material and requires full investigation.

Step 2: Investigation (30 days)
If potentially material:

- Verification body initiates formal investigation
- QET Producer provides all relevant information and data
- Calculations are revised with corrected inputs
- Impact on carbon intensity is quantified
- Root cause analysis is conducted

Step 3: Determination (15 days)
Verification body determines:

- Whether misstatement is material (>5% impact on CI)
- Whether verification opinion remains valid
- Whether amended verification statement is required
- Whether QET tokens must be recalled or adjusted

Step 4: Corrective Action (45 days)
Based on determination:

- **Non-material:** Document finding and implement preventive measures for future
- **Material - Verification Error:** Issue amended verification statement with corrected values
- **Material - Producer Error:** Original verification statement stands but Producer must issue corrective disclosure
- **Material - Fraud:** Verification opinion withdrawn, tokens flagged for recall

13.3 Amended Verification Statements

When an amended verification statement is required:

Content Requirements:

- Clear identification as "Amended Verification Statement"
- Reference to original statement with date
- Complete description of error or omission
- Revised emission values and carbon intensity
- Explanation of materiality determination
- Revised verification opinion if different
- Effective date of amendment

Distribution:

- QET Producer
- QET Registry
- All known token holders
- Public disclosure via Registry website

13.4 Token Adjustment Procedures

When material facts require token value adjustment:

13.4.1 Upward Adjustment (CI Increase)

If actual CI is higher than originally verified:

- Tokens remain valid but with corrected CI value
- Registry updates token metadata with amended CI
- Token holders notified of adjustment
- Compliance implications assessed (may affect regulatory credit value)
- Producer may need to issue additional tokens if quantity-based errors

13.4.2 Downward Adjustment (CI Decrease)

If actual CI is lower than originally verified:

- Tokens retain original (conservative) CI value OR
- Producer may request token reissuance with improved CI
- Registry updates records
- No adverse impact on token holders

13.4.3 Token Recall

In cases of fraud or fundamental invalidity:

- Registry flags affected tokens as invalid
- Token holders notified immediately
- Tokens cannot be transferred or retired
- Producer may be suspended from Registry
- Legal and financial remedies pursued

13.5 Prevention of Recurrence

For all material post-verification issues, Producer must:

- Conduct root cause analysis
- Implement corrective actions
- Update procedures and training
- Document lessons learned
- Demonstrate effectiveness in subsequent verification
- Consider third-party process audit if systematic failures identified

13.6 Regulatory Notifications

When QET-Ethanol tokens are used for regulatory compliance, material post-verification issues must be reported to:

- CARB (for LCFS compliance) within 10 days
- EPA (for RFS compliance) within 30 days
- European Commission (for RED compliance) within 30 days
- Other relevant authorities per applicable regulations

Failure to report may result in regulatory penalties separate from QET implications.

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14. Roles, Responsibilities, and Workflow in QET-Ethanol Production

14.1 Stakeholder Roles

14.1.1 QET Producer

Definition: The legal entity that operates the ethanol production facility and is responsible for GHG quantification, verification, and QET token generation.

Primary Responsibilities:

- Operate ethanol production facility in compliance with applicable regulations
- Implement data collection and management systems
- Quantify GHG emissions following this methodology
- Prepare GHG assertion for verification
- Contract with accredited verification body
- Provide verifier access to facility, personnel, and documentation
- Implement corrective actions for non-conformances
- Submit verified data to QET Registry
- Maintain records for required retention period

- Report material facts discovered after verification
- Market and transfer QET tokens in accordance with intended use

Personnel Requirements:

- Designated responsible party with authority to certify data accuracy
- Environmental/sustainability manager with GHG expertise
- Operations personnel trained in data collection
- Laboratory personnel for quality control
- IT staff for data management systems

14.1.2 Verification Body

Definition: An accredited third-party organization conforming to ISO 14065:2020 that conducts independent verification of GHG assertions.

Primary Responsibilities:

- Maintain ISO 14065 accreditation
- Assemble qualified verification team
- Conduct verification per ISO 14064-3 and this methodology
- Plan and execute site visits
- Gather and evaluate evidence
- Issue verification statement
- Maintain independence and impartiality
- Participate in independent review process
- Retain verification records for 7 years
- Report verification issues to accreditation body when required

14.1.3 QET Registry Operator

Definition: The organization that operates the QET Registry system for token issuance, tracking, transfer, and retirement.

Primary Responsibilities:

- Maintain secure registry platform
- Validate verification statements before token issuance
- Assign unique token identifiers
- Record tokens on blockchain ledger
- Enable token transfers between account holders
- Process token retirements
- Publish public disclosure information
- Maintain audit trail of all transactions
- Interface with regulatory registries when applicable

- Implement security and fraud prevention measures
- Provide customer support to registry participants

14.1.4 Token Holder

Definition: Entity that owns QET-Ethanol tokens in their registry account, which may include ethanol producers, fuel blenders, obligated parties, voluntary buyers, or end consumers.

Primary Responsibilities:

- Maintain active registry account
- Transfer tokens only through registry system
- Retire tokens to make environmental claims
- Avoid double-counting of environmental attributes
- Comply with terms and conditions of registry
- Report any suspected fraud or token invalidity
- Maintain records of token transactions for auditing purposes

14.1.5 Independent Reviewer

Definition: Qualified technical expert who reviews verification findings independently of the verification team.

Primary Responsibilities:

- Review verification documentation for completeness and quality
- Assess appropriateness of verification opinion
- Identify gaps or areas requiring additional evidence
- Approve verification findings or escalate concerns
- Maintain independence from verification engagement
- Document review process and conclusions

14.1.6 Accreditation Body

Definition: Organization that assesses and accredits verification bodies to ISO 14065:2020 (e.g., ANAB, UKAS).

Primary Responsibilities:

- Accredit verification bodies to ISO 14065
- Conduct surveillance and reassessment audits
- Witness verification activities
- Investigate complaints against verification bodies
- Suspend or withdraw accreditation for non-compliance
- Maintain public records of accredited bodies

14.1.7 Regulatory Authority (when applicable)

Definition: Government agency administering compliance program using QET-Ethanol tokens (e.g., CARB for LCFS, EPA for RFS).

Responsibilities:

- Establish carbon intensity thresholds and compliance requirements
- Review and approve fuel pathways
- Monitor compliance with program rules
- Audit token retirements and claims
- Enforce regulations and assess penalties
- Provide guidance on program implementation

14.2 QET-Ethanol Production Workflow

Phase 1: Preparation and Data Collection (Ongoing)

Timeline: Continuous during reporting period

Activities:

1. Facility operates ethanol production processes
2. Data collection systems record:
    - Ethanol production volumes (daily)
    - Feedstock inputs (each delivery)
    - Energy consumption (hourly or daily)
    - Co-product generation (daily)
    - Process parameters (continuous or batch)
3. Laboratory analyzes:
    - Ethanol purity and moisture
    - Feedstock composition
    - Co-product specifications
4. Operations staff maintain:
    - Equipment calibration records
    - Maintenance logs
    - Quality control documentation
5. Environmental staff monitor:
    - Emissions sources
    - Compliance with permits
    - Changes to processes or boundaries

Deliverables: Compiled production and emissions data for reporting period

Phase 2: GHG Quantification (Month after reporting period)

Timeline: 30 days after reporting period end

Activities:

1. Environmental/sustainability staff aggregate all activity data
2. Apply emission factors and calculation methodologies per this document
3. Calculate carbon intensity:
    - Feedstock emissions
    - Facility emissions
    - Co-product allocation
    - Overall CI (gCO_2e/MJ)
4. Assess uncertainty for each emission source
5. Prepare detailed calculation spreadsheets
6. Document all assumptions and data sources
7. Conduct internal QA review
8. Draft GHG assertion document

Deliverables: Draft GHG assertion with supporting calculations

Phase 3: Pre-Verification Review (2 weeks)

Timeline: 2 weeks before verification engagement

Activities:

1. QET Producer submits documentation to verification body:
    - GHG assertion
    - Supporting data and calculations
    - Facility description
    - Previous verification reports
2. Verification body conducts preliminary review:
    - Completeness check
    - Methodology conformance assessment
    - Risk identification
3. Verifier requests additional documentation if needed
4. Verification team assembled
5. Verification plan developed:
    - Site visit schedule
    - Sampling approach
    - Evidence requirements
6. Logistics arranged for site visit

Deliverables: Verification plan and site visit schedule

Phase 4: Verification Engagement (2-4 weeks)

Timeline: 2-4 weeks including site visit

Activities:

1. Opening meeting with facility management
2. Site visit conducted (1-3 days):
   - Facility tour
   - Equipment inspection
   - Personnel interviews
   - Document review
   - Observation of data collection procedures
3. Desk review activities:
   - Detailed calculation checking
   - Data testing and sampling
   - Uncertainty assessment
   - External confirmations
   - Regulatory compliance review
4. Findings documented:
   - Non-conformances identified
   - Opportunities for improvement noted
5. Closing meeting with facility:
   - Present preliminary findings
   - Discuss corrective actions needed
6. Producer implements corrective actions
7. Verifier evaluates corrective actions
8. Draft verification statement prepared

Deliverables: Draft verification statement with findings

Phase 5: Independent Review (1 week)

Timeline: 1 week for review and resolution

Activities:

1. Verification file submitted to independent reviewer
2. Reviewer conducts comprehensive assessment:
   - Verification planning adequacy
   - Evidence sufficiency
   - Technical accuracy
   - Opinion appropriateness
3. Reviewer issues comments and questions
4. Lead verifier responds with additional evidence or explanation

5. Disagreements resolved or escalated
6. Reviewer approves verification findings
7. Final verification statement issued

Deliverables: Final verification statement with independent review approval

Phase 6: Registry Submission and Token Issuance (1-2 weeks)

Timeline: 1-2 weeks after verification completion

Activities:

1. Calculate token quantity:

- Convert ethanol volume to mass: Volume (gal) × 2.987 kg/gal = Total kg
- Determine token quantity: Round down to whole kg units
- Example: 100,000 gallons × 2.987 = 298,700 kg = 298,700 tokens
- Calculate production fees: 298,700 kg × $0.0008 = $238.96

2. Prepare registry submission package:

- Complete JSON data structure with mass-based metrics
- Verification statement PDF with accreditation documentation
- GHG assertion document with calculations
- Mass-to-volume conversion worksheet
- Carbon intensity in all required units (per gallon, per kg, per MJ)
- Platform fee payment confirmation
- Service tier selection (Standard or EARN Premium)

3. Submit to EarnDLT Registry:

- Online submission portal
- Automated data validation
- Fee payment processing (ACH or wire)
- Account authentication via Dun & Bradstreet

4. Registry validation process:

- Data structure compliance with mass-based QET standards
- Verification statement authenticity check
- Accreditation body confirmation
- Mass calculation accuracy: gallons × 2.987 kg/gal
- Carbon intensity unit consistency across all metrics
- Platform fee calculation verification
- Completeness check (all required fields)

5. Token generation:

- Registry assigns unique token identifiers
- Format: QET-ETH-[YYYYMMDD]-[BatchID]-[Serial Range]
- Each token ID mapped to 1 kg ethanol mass
- Batch size: 298,700 tokens for 100,000 gallon example
- Token metadata includes:
    - Carbon intensity per kg ($kgCO_2e/kg$)
    - Volumetric equivalence (gallons represented)
    - Feedstock type and origin
    - Production facility identification
    - Verification details

6. Blockchain recording:

- Token metadata immutably recorded on blockchain
- Unique cryptographic hash generated
- Platform fees deducted: $238.96 production fee
- Transaction hash provided for audit trail
- Public disclosure information published

7. Token issuance to producer account:

- 298,700 QET-Ethanol tokens credited to Producer's EarnDLT account
- Account dashboard updated with:
    - Token inventory (kg basis)
    - Volumetric equivalent (gallons)
    - Average carbon intensity
    - Available for transfer or marketplace listing
- Transfer fees apply: $0.0004/kg per transfer transaction

8. Post-issuance options:

- Standard Tier: List on Greentruth marketplace (mandatory)
- EARN Premium: Direct bilateral transactions or optional marketplace
- Transfer to buyers (transfer fees apply per transaction)
- Retire for environmental claims
- Hold for regulatory compliance submission

Deliverables:

- 298,700 active QET-Ethanol tokens in EarnDLT registry
- Each token = 1 kg ethanol with verified carbon footprint
- Total volume represented: 100,000 gallons
- Carbon intensity: 0.720 $kgCO_2e/kg$ (example)
- Platform fees paid: $238.96 (production only)

Phase 7: Token Lifecycle Management (Ongoing)

Timeline: Until token retirement

Activities:

1. Token holder manages tokens:
   - Holds in registry account
   - Transfers to buyers
   - Retires for environmental claims
   - Uses for regulatory compliance
2. Registry maintains transaction records
3. Public disclosure updated for retirements
4. Token holder avoids double-counting
5. Environmental claims documented with retired token evidence

Deliverables: Retired tokens supporting environmental claims

14.3 Communication Protocols

14.3.1 Producer-Verifier Communication

Pre-Verification:

- Formal engagement letter defining scope, timeline, and fees
- Kickoff meeting to review approach and logistics
- Document sharing via secure portal

During Verification:

- Daily debriefs during site visit
- Formal request for information (RFI) process
- Documented interview summaries
- Draft findings shared for factual accuracy review

Post-Verification:

- Final verification statement delivered
- Corrective action tracking
- Annual follow-up for ongoing relationship

14.3.2 Producer-Registry Communication

- Electronic submission system for all documents

- Automated validation feedback
- Support tickets for technical issues
- Quarterly account statements
- Notifications for material changes or issues

14.3.3 Registry-Token Holder Communication

- Account portal for transactions
- Email notifications for transfers and retirements
- Public API for programmatic access
- Customer support via phone/email
- Regular platform updates and announcements

14.4 Timeline Summary

Phase	Duration	Key Milestone
Data Collection	Ongoing (1-12 months)	Production data compiled
GHG Quantification	30 days	GHG assertion complete
Pre-Verification	14 days	Verification plan approved
Verification	14-28 days	Verification statement issued
Independent Review	7 days	Review approval obtained
Registry Submission	7-14 days	Tokens issued
Total Timeline	**~90-120 days**	**From reporting period end to token issuance**

14.5 Cost Considerations

QET Producer Costs:

One-Time Implementation:

- Data management systems and equipment: $50,000-$200,000
- Initial verification setup and planning: $10,000-$25,000
- Staff training on QET methodology: $5,000-$15,000

- EarnDLT platform software and integration: $0 (included)
- EarnDLT facilitated business verification (Dun & Bradstreet): $0 (included)

Annual Recurring Costs:

- Personnel time for data collection and quantification: $20,000-$50,000
- Annual verification services: $15,000-$75,000 (depends on facility size)
- Sustainability certifications (RSB, ISCC, Bonsucro): $10,000-$30,000
- Quality control and laboratory analysis: $5,000-$20,000

EarnDLT Platform Fees (Mass-Based QET):

Fee Type	Rate	Example (100k gal/month)	Annual (100M gal)
Production Fee	$0.0008/kg	$238.96/month	$2,868
Transfer Fee	$0.0004/kg	$119.48 per transfer	Varies by transactions

Fee Analysis Per Gallon:

- Production: $0.002389/gallon
- Transfer: $0.001195/gallon per transfer
- Total (prod + 2 transfers): $0.004779/gallon
- As percentage of ethanol value: 0.19% (assuming $2.50/gal market price)

---

15. Appendices

Appendix A: Complete JSON Schema Example

json


```json
{
  "tokenType": "QET-Ethanol",
  "version": "1.0",
  "tokenID": "QET-ETH-20251031-0001-A1B2C3",
  "issuanceDate": "2025-10-31T18:00:00Z",
  "reportingPeriod": {
    "startDate": "2025-10-01T00:00:00Z",
    "endDate": "2025-10-31T23:59:59Z",
    "description": "October 2025 production"
  },
```

```
"serialNumberRange": {
  "startSerial": "ETH-2025-10-000001",
  "endSerial": "ETH-2025-10-050000",
  "totalTokens": 50000
},
"facility": {
  "facilityID": "EPA-GHGRP-1234567",
  "facilityName": "GreenFuel Ethanol LLC",
  "operatorName": "Sustainable Energy Corporation",
  "address": {
    "street": "1000 Renewable Way",
    "city": "Cornville",
    "state": "Iowa",
    "postalCode": "50001",
    "country": "United States"
  },
  "coordinates": {
    "latitude": 42.0345,
    "longitude": -93.6123
  },
  "facilityType": "Dry Mill Corn Ethanol with CHP",
  "operationalStatus": "Active",
  "commissioningDate": "2018-03-15",
  "certifications": [
    {
      "type": "EPA-RFS-Producer",
      "number": "12345-RFS-P",
      "validFrom": "2024-01-01",
      "validTo": "2026-12-31"
    },
    {
      "type": "CARB-LCFS-Pathway",
      "number": "CA-ETH-67890",
      "validFrom": "2023-05-15",
      "validTo": "2028-05-15",
      "certifiedCI": 28.2
    },
    {
```

```
        "type": "RSB-Advanced-Fuels",
        "number": "RSB-AF-2025-12345",
        "validFrom": "2025-01-01",
        "validTo": "2025-12-31"
      }
    ],
    "productionCapacity": {
      "value": 100,
      "unit": "million gallons per year"
    }
  },
  "production": {
    "ethanolVolume": {
      "value": 8500000,
      "unit": "gallons",
      "specification": "anhydrous",
      "purity": 99.6,
      "measurement": "Calibrated Coriolis flow meter with temperature
compensation",
      "uncertainty": 1.5
    },
    "energyContent": {
      "total": 684505000,
      "unit": "MJ",
      "LHV": 80.53,
      "LHVUnit": "MJ/gallon"
    },
    "productionProcess": "Enzymatic dry mill fermentation with
multi-effect distillation",
    "fermentationDetails": {
      "organism": "Saccharomyces cerevisiae",
      "fermentationTime": "48-52 hours",
      "yieldEfficiency": 92.5
    },
    "processConfiguration": {
      "millType": "Dry mill",
      "cookingMethod": "Jet cooking with liquefaction",
      "fermentationType": "Batch",
```

```
      "distillationColumns": 3,
      "dehydrationMethod": "Molecular sieve"
    }
  },
  "feedstock": {
    "primaryFeedstock": {
      "type": "Corn grain",
      "classification": "First-generation starch feedstock",
      "quantity": {
        "value": 23800,
        "unit": "metric tons",
        "moisture": 15.5
      },
      "conversionRatio": {
        "value": 2.8,
        "unit": "gallons ethanol per bushel corn"
      },
      "origin": {
        "region": "Iowa, United States",
        "counties": ["Story County", "Boone County", "Hamilton
County"],
        "averageTransportDistance": {
          "value": 75,
          "unit": "km"
        },
        "transportMode": "Truck",
        "sustainabilityCertification": {
          "scheme": "RSB-EU",
          "certificateNumber": "RSB-EU-2025-54321",
          "validity": "2025-01-01 to 2025-12-31"
        }
      },
      "cultivationEmissions": {
        "value": 340,
        "unit": "kgCO2e per metric ton",
        "methodology": "CA-GREET 3.0 Iowa corn farming default",
        "breakdown": {
          "fertilizer": 220,
```

```
        "fieldOperations": 75,
        "N2O_direct": 35,
        "N2O_indirect": 10
      }
    }
  },
  "processInputs": {
    "enzymes": [
      {
        "type": "Alpha-amylase",
        "quantity": {
          "value": 2040,
          "unit": "kg"
        },
        "emissionFactor": 3.2,
        "totalEmissions": 6528
      },
      {
        "type": "Glucoamylase",
        "quantity": {
          "value": 1360,
          "unit": "kg"
        },
        "emissionFactor": 3.2,
        "totalEmissions": 4352
      }
    ],
    "chemicals": [
      {
        "name": "Sulfuric acid",
        "purpose": "pH adjustment",
        "quantity": {
          "value": 425,
          "unit": "kg"
        },
        "emissionFactor": 0.15,
        "totalEmissions": 64
      },
```

```
        {
          "name": "Ammonia (anhydrous)",
          "purpose": "pH adjustment and yeast nutrient",
          "quantity": {
            "value": 850,
            "unit": "kg"
          },
          "emissionFactor": 2.2,
          "totalEmissions": 1870
        }
      ],
      "yeast": {
        "type": "Active dry yeast",
        "quantity": {
          "value": 170,
          "unit": "kg"
        },
        "emissionFactor": 1.8,
        "totalEmissions": 306
      }
    }
  },
  "coProducts": [
    {
      "name": "Distillers Dried Grains with Solubles (DDGS)",
      "quantity": {
        "value": 7225,
        "unit": "metric tons",
        "moisture": 10.5,
        "dryBasis": 6466
      },
      "composition": {
        "protein": 27.5,
        "fat": 10.2,
        "fiber": 8.5
      },
      "energyContent": {
        "total": 122854,
```

```
        "unit": "GJ",
        "LHV": 19.0,
        "LHVUnit": "MJ/kg dry basis"
      },
      "disposition": "Sold as livestock feed to regional dairy and
beef operations",
      "market": "Local market within 200 km radius",
      "allocationMethod": "Energy allocation per LCFS requirements",
      "allocationFactor": 0.152
    },
    {
      "name": "Corn oil",
      "quantity": {
        "value": 204,
        "unit": "metric tons"
      },
      "energyContent": {
        "total": 7650,
        "unit": "GJ",
        "LHV": 37.5,
        "LHVUnit": "MJ/kg"
      },
      "disposition": "Sold to biodiesel producer",
      "allocationFactor": 0.011
    }
  ],
  "emissions": {
    "carbonIntensity": {
      "value": 28.2,
      "unit": "gCO2e/MJ",
      "calculationMethod": "ISO 14044 lifecycle assessment with
energy-based co-product allocation per CARB LCFS methodology",
      "uncertainty": 7.8,
      "baselineComparison": {
        "baseline": "CARB LCFS gasoline baseline 2025",
        "baselineCI": 95.86,
        "baselineUnit": "gCO2e/MJ",
        "reductionAbsolute": 67.66,
```

```
        "reductionPercentage": 70.6
      }
    },
    "totalEmissions": {
      "gross": {
        "value": 23186000,
        "unit": "kgCO2e",
        "scope1": 16842000,
        "scope2": 1026000,
        "scope3": 5318000
      },
      "allocated": {
        "value": 19313000,
        "unit": "kgCO2e",
        "allocationFactor": 0.833,
        "perGallon": 2.27,
        "perMJ": 28.2
      },
      "biogenicCO2": {
        "value": 16320000,
        "unit": "kgCO2",
        "counted": false,
        "note": "Fermentation CO2 not counted per IPCC biogenic carbon accounting"
      }
    },
    "emissionsBySource": {
      "feedstock": {
        "cultivation": {
          "value": 8092000,
          "unit": "kgCO2e",
          "uncertainty": 18,
          "breakdown": {
            "fertilizer_production": 5236000,
            "field_operations": 1785000,
            "N2O_direct_soil": 833000,
            "N2O_indirect": 238000
          }
```

```
        },
        "drying": {
          "value": 595000,
          "unit": "kgCO2e",
          "methodology": "Natural gas drying from 22% to 15.5%
moisture"
        },
        "transport": {
          "value": 1190000,
          "unit": "kgCO2e",
          "distance": 75,
          "distanceUnit": "km",
          "mode": "Heavy-duty truck",
          "emissionFactor": 0.062,
          "emissionFactorUnit": "kgCO2e per ton-km"
        }
      },
      "processInputs": {
        "enzymes": {
          "value": 10880,
          "unit": "kgCO2e"
        },
        "chemicals": {
          "value": 2240,
          "unit": "kgCO2e"
        },
        "yeast": {
          "value": 306,
          "unit": "kgCO2e"
        }
      },
      "facility": {
        "naturalGas": {
          "combustion": {
            "value": 13650000,
            "unit": "kgCO2e",
            "consumption": 243380,
            "consumptionUnit": "mmBTU",
```

```
            "purpose": "Process heat for cooking, distillation, DDGS
drying",
            "emissionFactor": 56.1,
            "emissionFactorUnit": "kgCO2e/mmBTU",
            "efficiency": 82,
            "uncertainty": 4.5
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        },
        "electricity": {
          "purchased": {
            "value": 1026000,
            "unit": "kgCO2e",
            "consumption": 1380000,
            "consumptionUnit": "kWh",
            "gridRegion": "MRO-West (eGRID2023)",
            "emissionFactor": 0.744,
            "emissionFactorUnit": "kgCO2e/kWh",
            "uncertainty": 8.2
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        "wastewater": {
          "value": 425000,
          "unit": "kgCO2e",
          "treatment": "Anaerobic digestion with biogas recovery",
          "CH4_emissions": 2857,
          "CH4_unit": "kgCH4",
          "N2O_emissions": 85,
          "N2O_unit": "kgN2O",
          "uncertainty": 28
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        "fugitive": {
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          "unit": "kgCO2e",
          "sources": [
            {
              "source": "Ethanol storage tanks",
              "emissions": 68000,
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              "controlMeasure": "Vapor recovery system (95%
efficient)"
            },
            {
              "source": "Loading operations",
              "emissions": 42500,
              "controlMeasure": "Submerged fill and vapor balance"
            },
            {
              "source": "Process vents",
              "emissions": 17000,
              "controlMeasure": "Scrubbers and thermal oxidizers"
            }
          ],
          "uncertainty": 22
        },
        "mobileEquipment": {
          "value": 85000,
          "unit": "kgCO2e",
          "description": "Forklifts, loaders, yard trucks",
          "fuelConsumption": 31800,
          "fuelUnit": "liters diesel",
          "uncertainty": 10
        }
      },
      "distribution": {
        "transport_to_terminal": {
          "value": 178500,
          "unit": "kgCO2e",
          "distance": 320,
          "distanceUnit": "km",
          "mode": "Rail",
          "emissionFactor": 0.022,
          "emissionFactorUnit": "kgCO2e per ton-km",
          "included": true,
          "note": "Transport to primary fuel terminal"
        }
      }
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    "ghgBreakdown": {
      "CO2": {
        "fossil": {
          "value": 21890000,
          "unit": "kgCO2"
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        "biogenic": {
          "value": 16320000,
          "unit": "kgCO2",
          "counted": false
        }
      },
      "CH4": {
        "value": 45360,
        "unit": "kgCH4",
        "CO2e": 1270080,
        "GWP": 28,
        "GWP_reference": "IPCC AR5 without climate-carbon feedbacks"
      },
      "N2O": {
        "value": 3887,
        "unit": "kgN2O",
        "CO2e": 1030055,
        "GWP": 265,
        "GWP_reference": "IPCC AR5 without climate-carbon feedbacks"
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    "allocationCalculation": {
      "method": "Energy allocation",
      "methodology_reference": "CARB LCFS §95488.6",
      "products": [
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          "product": "Ethanol",
          "energyContent": 684505,
          "unit": "GJ",
          "allocationFactor": 0.833,
          "allocatedEmissions": 19313000
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        },
        {
          "product": "DDGS",
          "energyContent": 122854,
          "unit": "GJ",
          "allocationFactor": 0.149,
          "allocatedEmissions": 3455000
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        {
          "product": "Corn oil",
          "energyContent": 7650,
          "unit": "GJ",
          "allocationFactor": 0.009,
          "allocatedEmissions": 209000
        },
        {
          "totalEnergy": 815009,
          "unit": "GJ",
          "totalAllocated": 22977000,
          "note": "Minor rounding differences in allocation"
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  "uncertainty": {
    "overallUncertainty": {
      "value": 7.8,
      "unit": "percent",
      "confidenceLevel": 95,
      "methodology": "Monte Carlo simulation with 10,000 iterations"
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    "sourceUncertainties": [
      {
        "source": "Ethanol production volume",
        "uncertainty": 1.5,
        "method": "Meter accuracy specification"
      },
      {
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        "source": "Feedstock quantity",
        "uncertainty": 3.2,
        "method": "Weigh scale calibration and testing"
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      {
        "source": "Natural gas consumption",
        "uncertainty": 4.5,
        "method": "Utility meter accuracy"
      },
      {
        "source": "Electricity consumption",
        "uncertainty": 8.2,
        "method": "Grid emission factor variability"
      },
      {
        "source": "Feedstock cultivation emissions",
        "uncertainty": 18.0,
        "method": "CA-GREET model uncertainty analysis"
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      {
        "source": "Wastewater emissions",
        "uncertainty": 28.0,
        "method": "IPCC Tier 2 default uncertainty range"
      }
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    "conservativeAdjustments": {
      "applied": false,
      "reason": "Overall uncertainty 7.8% is below 8% target
threshold"
    }
  },
  "verification": {
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      "name": "SCS Global Services",
      "accreditationBody": "ANSI National Accreditation Board (ANAB)",
      "accreditationNumber": "ANAB-VB-1234",
      "accreditationScope": "ISO 14065:2020 - GHG verification for
biofuels and renewable energy",
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"accreditationExpiry": "2027-06-30",
"address": {
"city": "Emeryville",
"state": "California",
"country": "United States"
}
},
"verificationTeam": {
"leadVerifier": {
"name": "Dr. Sarah Johnson, P.E.",
"credentials": [
"Professional Engineer (Chemical)",
"ISO 14064-3 Lead Verifier",
"CARB Approved Verifier"
],
"verifierID": "SCS-LV-2024-SJ-089",
"experience": "12 years in GHG verification, 8 years in biofuels sector"
},
"technicalSpecialists": [
{
"name": "Michael Chen",
"role": "Agricultural emissions specialist",
"credentials": "Agronomist, LCA practitioner"
},
{
"name": "Emily Rodriguez",
"role": "Process engineer",
"credentials": "Chemical Engineer, 15 years ethanol industry experience"
}
],
"independentReviewer": {
"name": "Dr. Robert Martinez",
"credentials": "ISO 14065 Technical Reviewer, 20 years GHG verification",
"reviewDate": "2025-10-28"
}

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  },
  "verificationStandard": "ISO 14064-3:2019",
  "assuranceLevel": "Reasonable",
  "materialityThreshold": {
    "value": 5.0,
    "unit": "percent",
    "basis": "Total allocated emissions"
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  "verificationActivities": {
    "siteVisit": {
      "conducted": true,
      "dates": ["2025-10-15", "2025-10-16"],
      "duration": "2 days",
      "participants": [
        "Dr. Sarah Johnson (Lead Verifier)",
        "Emily Rodriguez (Process Specialist)",
        "John Davis (Facility Manager)",
        "Maria Santos (Environmental Manager)"
      ]
    },
    "documentReview": {
      "completed": true,
      "documentsReviewed": 237,
      "keyDocuments": [
        "Production logs (October 2025)",
        "Feedstock receiving records",
        "Utility bills (natural gas, electricity)",
        "DDGS sales records",
        "Laboratory analytical results",
        "Equipment calibration certificates",
        "EPA GHGRP Annual Report 2024",
        "CARB LCFS Quarterly Report Q3-2025"
      ]
    },
    "dataTesting": {
      "completed": true,
      "samplingRate": {
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          "feedstockInputs": 12.0,
          "energyConsumption": 25.0,
          "calculations": 100.0
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        "discrepanciesResolved": 2
      },
      "interviews": {
        "conducted": 12,
        "personnel": [
          "Facility Manager",
          "Environmental Manager",
          "Operations Supervisor",
          "Laboratory Manager",
          "Maintenance Supervisor",
          "Process Control Engineer",
          "Quality Assurance Manager"
        ]
      }
    },
    "findings": {
      "nonConformances": {
        "major": 0,
        "minor": 2
      },
      "opportunitiesForImprovement": 5,
      "summary": "Two minor non-conformances identified related to
documentation completeness for enzyme procurement records and
calibration record filing. Both corrected during verification period.
No material misstatements identified."
    },
    "verificationDate": "2025-10-30",
    "verificationOpinion": "Based on the verification activities
conducted in accordance with ISO 14064-3:2019, it is our professional
opinion that the GHG assertion for GreenFuel Ethanol LLC for the
reporting period October 1-31, 2025 is free from material misstatement
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and conforms to the Methodology for the Production and Verification of Ethanol Quantified Emissions Tokens in Accordance with ISO 14064-3.",
    "verificationStatementURL":
"https://registry.qet.io/verification-statements/QET-ETH-20251031-0001-A1B2C3.pdf",
    "verificationStatementHash":
"0xabcdef1234567890fedcba0987654321abcdef1234567890fedcba0987654321"
  },
  "compliance": {
    "applicablePrograms": [
      {
        "program": "California LCFS",
        "authority": "California Air Resources Board (CARB)",
        "pathwayCode": "CA-ETH-67890",
        "pathwayType": "Corn ethanol with DDGS",
        "certifiedCI": 28.2,
        "certificationDate": "2023-05-15",
        "expirationDate": "2028-05-15",
        "complianceYear": 2025,
        "creditsGenerated": true,
        "creditCalculation": "Based on CI differential from baseline"
      },
      {
        "program": "Federal Renewable Fuel Standard (RFS2)",
        "authority": "U.S. Environmental Protection Agency (EPA