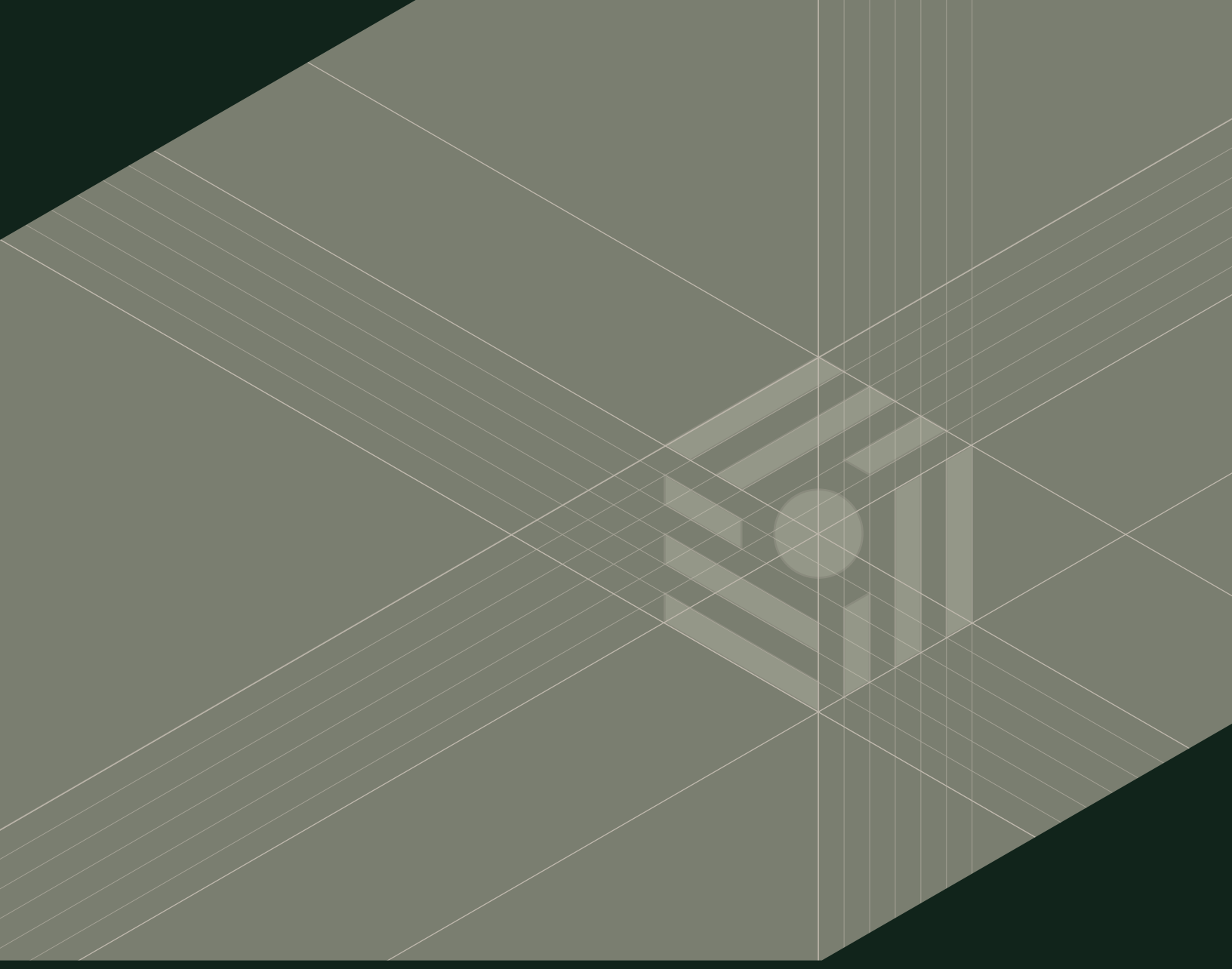

1.0
version

Methodology for the Production and Verification of Renewable Natural Gas Quantified Emissions Token Thermal Certificates (QET-RNG) — $kgCO_2e/MMBtu$

This methodology defines QET-RNG Thermal Certificates, measuring GHG intensity in $kgCO_2e/MMBtu$, with each token representing 1 MMBtu of verified renewable natural gas. Tokens are issued and tracked through the EarnDLT registry, providing immutable records and transparent chain-of-custody.

greentruth

QRNG

Methodology for the Production and Verification of Renewable Natural Gas Quantified Emissions Token Thermal Certificates (QET-RNG) — $kgCO_2e/MMBtu$ v1.0

Executive Summary

This methodology establishes a comprehensive framework for producing, quantifying, and verifying Renewable Natural Gas Quantified Emissions Token® Thermal Certificates (QET-RNG), ensuring all greenhouse gas (GHG) intensities are measured in $kgCO_2e/MMBtu$. Each QET-RNG represents 1 MMBtu of thermal energy from renewable natural gas with verified carbon intensity, designed to provide precise, audit-friendly environmental attribute certificates aligned with ISO 14064-3 verification requirements and directly referencing the EarnDLT QET core production and verification methodology. The QET-RNG tokens are issued, managed, and tracked on the EarnDLT blockchain-based registry platform, providing immutable record-keeping and transparent chain-of-custody documentation.

California Market Note: Producers intending to sell RNG thermal certificates into California's Low Carbon Fuel Standard program must enhance their QET-RNG tokens using the companion *QET-LCFS Extension Methodology* to ensure full regulatory compliance and credit generation capability.

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1. Introduction and Scope

Purpose: Provide a complete framework for creating QET-RNGs with verified carbon intensity (CI), each representing 1 MMBtu of renewable natural gas thermal energy. This methodology enables customers to demonstrate the environmental benefits of RNG consumption through tokenized environmental attributes, including avoided methane emissions from landfills and other organic waste sources.

Reference: All cross-references to QET core methodology ("*Methodology for the Production and Verification of Quantified Emissions Tokens (QETs) in Accordance with ISO 14064-3*") cite section numbers for traceability.

2. Normative References

- **ISO 14064-3:2019** (Verification and validation requirements
- **QET Methodology (EarnDLT)**: Sections 4 (system boundaries), 5 (quantification), 6 (uncertainty), 7 (data structure), 8 (verification)
- **QET-LCFS Extension Methodology**: Required for California LCFS market participation
- **California Air Resources Board (CARB) Low Carbon Fuel Standard**
- **CA-GREET 3.0 Model**
- **EPA Renewable Fuel Standard (RFS)**
- **ISO 14067:2018** (Carbon footprint of products)
- **North American Energy Standards Board (NAESB) Business Practice Standards**
- **GHG Protocol Corporate Standard**
- **ASTM Standards for Renewable Energy Certificates**
- **Unit Standardization:** All GHG intensities expressed in $kgCO_2e/MMBtu$ consistent with EarnDLT QET-T thermal certificate methodologies
- **CCR Title 17, Section 95502**: CARB accreditation requirements for verification bodies, lead verifiers, and verifiers
- **CCR Title 17, Section 95500**: Requirements for validation and verification services under LCFS
- **US Department of Energy R&D GREET Model**: GREET1_2024_Rev1.xlsm, Argonne National Laboratory
- **GREET Transport Parameters**: T_D_Flowcharts!AC378 - US Average Pipeline transmission factors

3. Terms and Definitions

3.1 QET-RNG (Renewable Natural Gas QET):

Digital token for 1 MMBtu of thermal energy from renewable natural gas with verified CI in $kgCO_2e/MMBtu$

3.2 Renewable Natural Gas (RNG):

Pipeline-quality biomethane derived from the anaerobic digestion or thermochemical conversion of organic waste materials, including landfill gas, agricultural waste, wastewater treatment biogas, and food waste.

3.3 Landfill Gas (LFG):

Biogas generated from the anaerobic decomposition of organic waste in landfills, consisting primarily of methane and carbon dioxide.

3.4 Avoided Emissions:

GHG reductions achieved by capturing and utilizing biogas that would otherwise be released to the atmosphere or flared.

3.5 Carbon Intensity (CI):

Lifecycle GHG emissions per unit of energy, expressed in $kgCO_2e/MMBtu$.

3.6 Environmental Attributes:

All credits, benefits, emissions reductions, environmental air quality credits, and allowances resulting from renewable gas production.

3.7 Biogas:

Renewable energy resource derived from anaerobic digestion of organic matter, comprised of methane, carbon dioxide, and associated gases.

3.8 EarnDLT Registry:

Blockchain-based platform for issuing, tracking, transferring, and retiring environmental attribute certificates with immutable record-keeping

3.9 QET Transfer Capability:

Optional functionality enabling QET holders to export certificates to external registries when beneficial for market access or customer requirements

3.10 Blockchain Immutability:

Cryptographic assurance that certificate records cannot be altered or falsified once recorded on the distributed ledger

4. System Boundaries and Scope

4.1 Boundary Definition

Following **QET Section 4.4** with specific adaptations for RNG systems:

Upstream:

- Feedstock collection and transport
- Waste diversion from landfills or other disposal methods
- Preprocessing and conditioning

Core Process:

- Biogas production through anaerobic digestion
- Gas cleaning and upgrading to pipeline quality
- Pipeline injection or direct use delivery
- On-site energy consumption for processing

Downstream:

- Pipeline transmission and distribution
- Avoided emissions from waste diversion
- End-use delivery (excluding combustion)

4.2 Inclusions and Exclusions

- **Included**: All emissions from feedstock collection through pipeline injection, including process energy, fugitive emissions, and avoided emissions credits
- **Excluded**: End-use combustion emissions (consistent with QET Section 4.4.2)

5. Quantification Methodology

5.1 Calculation Framework

Following **QET Section 5** methodology:

text

$$\text{QET-RNG CI } (kgCO_2e/MMBtu) = (\text{Process Emissions} - \text{Avoided Emissions}) / \text{Net RNG Energy Production } (MMBtu)$$

All emissions are normalized to $kgCO_2e$ per **QET Section 5.5**.

5.1.1 Unit Conversion Protocol

All emission factors and carbon intensity values must be converted from grams CO_2 equivalent to kilograms CO_2 equivalent using the standard conversion factor:

$$CI\ (kgCO_2e/MMBtu) = CI\ (gCO_2e/MMBtu) \div 1000$$

Conversion factors for common energy units:

- 1 MMBtu (HHV) = 1.055056 MJ
- 1 kg = 1000 g
- Standard conversion: $gCO_2e/MJ \times 1.055056 \div 1000 = kgCO_2e/MMBtu$

5.1.2 LCFS Unit Conversion Requirements

When enhancing QET-RNG tokens for California LCFS compliance:

Standard Conversion Formula:

$$CI\ (gCO_2e/MJ) = CI\ (kgCO_2e/MMBtu) \times 1000 \div 1.055056$$

Example Conversion:

- RNG Token CI: -51.29 $kgCO_2e/MMBtu$
- LCFS CI: -48.60 gCO_2e/MJ

Verification Requirement: Both unit expressions must be validated during LCFS enhancement to ensure mathematical consistency.

5.2 Dual Carbon Intensity Calculation Framework

QET-RNG tokens utilize a dual calculation approach to accommodate both bilateral and marketplace transactions with accurate environmental impact accounting.

5.2.1 Base Production Carbon Intensity

All QET-RNG tokens are initially issued with a **Base Production Carbon Intensity** that excludes transport emissions:

$$\text{Base Production CI } (kgCO_2e/MMBtu) = (\text{Biogas Extraction} + \text{Gas Processing} + \text{Fugitive Emissions} - \text{Avoided Emissions}) \,/\, \text{Net RNG Energy Production } (MMBtu)$$

Components:

- Biogas extraction and processing: Variable by electricity grid mix
- Gas upgrading and conditioning: Fixed facility-based emissions
- Fugitive emissions: 1% loss factor applied
- Avoided emissions: Calculated per CARB Tier 1 methodology
- **Excluded**: Pipeline transport and delivery emissions

5.2.2 Transaction-Specific Final Carbon Intensity

For Bilateral Transactions:

Transport emissions calculated using known delivery endpoint at time of token issuance:

`Final CI (kgCO₂e/MMBtu) = Base Production CI + Static Transport Emissions`

For GreenTruth Marketplace Transactions:

Transport emissions calculated dynamically at the time of order placement:

`Final CI (kgCO₂e/MMBtu) = Base Production CI + Dynamic Transport Emissions`

Where Dynamic Transport Emissions are calculated using the verified algorithm in Section 5.2.3.

5.2.3 Dynamic Transport Emission Calculation Algorithm

Verified Calculation Engine:

`Transport Emissions (kgCO₂e/MMBtu) = Distance × 0.004632566667`

Verified Parameters (validated annually):

GREET-Based Distance Factor: `` `0.004632566667 kgCO₂e per mile per MMBtu` ``

- **Source**: US Department of Energy R&D GREET Model, version GREET1_2024_Rev1.xlsm
- **Reference**: T_D_Flowcharts!AC378 - US Average Pipeline distance: 600 miles at 2.78 kg/MMBtu transmission total
- **Calculation**: 2.78 kg/MMBtu ÷ 600 miles = 0.004632566667 kg CO_2e per mile per MMBtu
- **Basis**: Comprehensive transmission factor including compression energy, venting, fugitive emissions, and pipeline transport
- **Validation**: Annual verification against current GREET model releases and EPA regulatory updates

Factor Validation Requirements:

- Annual verification of GREET-based emission factors against regulatory sources
- Cross-reference with EPA GHG Inventory annual updates for transmission systems
- Compliance verification with CA-GREET model updates for California market transactions
- Documentation of the GREET version used and the regulatory basis for factor selection

Alternative Sources for California LCFS Compliance:

When QET-RNG tokens are enhanced for CARB LCFS compliance, the following sources take precedence:

- **CA-GREET 4.0 Model**: Latest version with California-specific pipeline infrastructure assumptions
- **CARB Lookup Table Pathways**: Updated transmission factors from CARB pathway determinations
- **LCFS Regulation Updates**: Current transmission factors per CCR Title 17, Section 95488.8

GIS Integration Requirements:

- Pipeline route calculation using verified mapping systems
- Distance measurement accuracy: ±2% maximum deviation

5.2.3.1 Example Calculation - Dynamic Transport Emissions

Scenario: GreenTruth marketplace transaction from Laubscher Meadows Landfill (California) to Denver, CO Distribution Hub

Given Parameters:

- **Base Production CI**: -65.15 $kgCO_2e$/MMBtu (verified annually)
- **Transport Distance**: 847.3 miles (calculated via GIS system)
- **GREET Distance Factor**: 0.004632566667 $kgCO_2e$ per mile per MMBtu

Example Calculation:

Step 1: Calculate Total Transport Emissions

$$\text{Transport Emissions} = \text{Distance} \times \text{GREET Distance Factor}$$
$$\text{Transport Emissions} = 847.3 \text{ miles} \times 0.004632566667 \text{ kgCO}_2\text{e/mile/MMBtu}$$
$$\text{Transport Emissions} = 3.925 \text{ kgCO}_2\text{e/MMBtu}$$

Step 2: Calculate Final Carbon Intensity

```
Final CI = Base Production CI + Transport Emissions
Final CI = -65.15 + 3.925
Final CI = -61.225 kgCO₂e/MMBtu
```

Comparison Example - Bilateral Transaction:

Scenario: Direct bilateral sale to Pacific Gas Pipeline Connection Point 7 (15.5 miles)

```
Transport Emissions = 15.5 miles × 0.004632566667 kgCO₂e/mile/MMBtu =
0.072 kgCO₂e/MMBtu

Final CI = -65.15 + 0.072 = -65.078 kgCO₂e/MMBtu
```

Impact Analysis:

- **Distance Impact**: Long-distance delivery (847.3 vs 15.5 miles) increases transport emissions by 3.853 $kgCO_2e/MMBtu$
- **Final CI Impact**: Minimal impact on carbon benefit due to GREET's comprehensive but conservative transmission factors
- **Market Transparency**: Simplified calculation provides clear, GREET-aligned environmental impact accounting

Quality Control Validation:

- **Distance Accuracy**: ±2% tolerance (847.3 miles ± 16.9 miles acceptable range)
- **Calculation Time**: <30 seconds for marketplace transaction completion
- **Algorithm Verification**: Annual verification confirms emission factor accuracy
- **Audit Trail**: Complete calculation documentation recorded on the EarnDLT blockchain

Real-Time Calculation Process:

1. **Buyer Order Placement**: Denver, CO delivery location specified
2. **GIS Distance Calculation**: 847.3 miles via verified pipeline route mapping
3. **Dynamic CI Calculation**: 3.925 $kgCO_2e/MMBtu$ transport emissions calculated
4. **Final CI Display**: -61.225 $kgCO_2e/MMBtu$ shown to buyer before order confirmation
5. **Order Confirmation**: Final CI locked and recorded permanently on blockchain
6. **Token Transfer**: Enhanced token with final CI transferred to buyer's wallet

6. Data Requirements

Following **QET Section 5.1.1**:

Required Primary Data:

- Biogas production volumes (scf at standard conditions)
- Methane content (% CH_4)
- Processing facility energy consumption (electricity kWh, natural gas MMBtu)
- Pipeline injection volumes (MMBtu HHV)
- Transport distances
- Fugitive emission measurements or estimates

Supporting Documentation:

- Gas meter readings and calibration records
- Utility bills for energy consumption
- Pipeline injection records
- Third-party verification reports
- Producer attestation formsRNGA-Producer-Attestation-Confidential-Example.pdf

7. Uncertainty Reporting Requirements

7.1 Sources of Uncertainty

Following **QET Section 6**

- **Measurement Uncertainty**: Gas meters, composition analysis, flow measurement
- **Parameter Uncertainty**: Emission factors, heating values, conversion factors
- **Model Uncertainty**: CA-GREET model limitations, allocation methodologies
- **Temporal Uncertainty**: Sampling frequency and representativeness
- **Spatial Uncertainty**: Regional emission factors and transport distances

7.2 Quantification Methods

Total Combined Uncertainty:

text

$$U_{total} = \sqrt{(U_1^2 + U_2^2 + ... + U^2)}$$

where each U_i represents independent uncertainty sources as percentages.

Confidence Level Calculation:

text

$$Confidence\ Level = 100\% - U_{total}$$

7.3 Target Uncertainty Thresholds

- Individual token batches: ±10% of mean CI value
- Aggregated portfolios: ±5% of mean CI value
- Exceeded thresholds require increased measurement frequency or precision

8. Verification Requirements

Aligned with **QET Section 8**:

8.1 Third-Party Verification Requirements

8.1.1 Standard QET-RNG Verification (Universal Requirements)

Base Production Verification (Annual):

- Annual verification by a qualified verifier experienced with RNG, LCA, and biogas systems
- Site visits for reasonable assurance engagements per **QET Section 14**
- Documentation review per **QET Section 8.1**
- Verification of the base production carbon intensity calculation methodology
- Validation of biogas production and processing systems
- Review of avoided emissions calculation procedures per CARB Tier 1 methodology
- Verification of facility measurement and monitoring systems

8.1.2 GreenTruth Marketplace Enhanced Verification

Additional Requirements for Dynamic CI Calculation:

For facilities participating in Greentruth marketplace transactions with dynamic environmental impact calculations:

- **Algorithm Verification**: Annual validation of transport emission calculation algorithms
- **GIS System Verification**: Accuracy verification for distance calculation systems (±2% tolerance)
- **Emission Factor Validation**: Verification of transport emission factors using EPA-approved methodologies
- **Quality Control Procedures**: Validation of automated calculation quality control systems
- **Exception Handling**: Verification of error detection and failover procedures

- **Audit Trail Systems**: Verification of blockchain documentation and calculation logging systems

8.1.3 CARB LCFS Enhanced Verification (Optional)

Verifier Qualification Hierarchy:

Tier 1: Standard QET-RNG Verification

- ISO 14064-3 qualified verifiers with RNG system experience
- Suitable for: Non-California market transactions, bilateral contracts, general market sales

Tier 2: CARB-Accredited Enhanced Verification

For producers intending to sell QET-RNG tokens for LCFS compliance in California markets:

- **CARB Accreditation Requirement**: Verifiers must maintain current CARB accreditation under the LCFS verification program per CCR Title 17, Section 95502
- **ISO 14065 Certification**: Verification bodies must hold ISO 14065 accreditation from an acceptable accreditation body
- **Technical Competence**: Demonstrated experience in CA-GREET modeling, fuel pathway analysis, and alternative fuel production technology

LCFS-Specific Requirements:

- CA-GREET algorithm compliance verification for dynamic transport calculations
- CARB pathway validation documentation review
- LCFS reporting system integration verification
- Dual methodology compliance (QET + LCFS requirements)

Tier 3: CARB Lead Verifier Certification

For pathway validation and enhanced marketplace functionality:

- CARB-accredited lead verifiers with fuel pathway certification experience per Section 95502(c)(4)
- Pathway validation capability for new CARB pathways
- Authority to validate dynamic calculation algorithms for LCFS compliance

8.1.4 Verification Scope Matrix

Understanding Verification Requirements by Token Type

The verification scope matrix below illustrates which verification components are required based on the intended use and market destination of QET-RNG tokens. This matrix helps producers and verifiers understand the specific requirements for different token configurations:

Verification Component Definitions:

- **Base Production CI**: Verification of facility-level carbon intensity calculations excluding transport emissions
- **Static Transport CI**: Verification of fixed transport emissions for known delivery endpoints (bilateral transactions)
- **Dynamic Algorithm**: Verification of automated calculation systems for variable transport emissions (marketplace transactions)
- **CA-GREET Compliance**: Verification of carbon intensity calculations using California's approved lifecycle assessment model
- **GIS System Accuracy**: Verification of geographic information systems used for distance calculations in dynamic CI
- **CARB Pathway Validation**: Verification of fuel pathway applications and carbon intensity calculations for LCFS compliance
- **LRT-CBTS Integration**: Verification of integration with California's Low Carbon Fuel Standard Reporting Tool and Credit Bank & Transfer System

Token Configuration Explanations:

- **Standard QET**: Basic QET-RNG tokens for bilateral transactions with known delivery endpoints, suitable for non-California markets
- **CARB Enhanced**: QET-RNG tokens prepared for potential California LCFS market participation, requiring CARB-accredited verification
- **Marketplace Dynamic**: QET-RNG tokens enabled for GreenTruth marketplace transactions with dynamic carbon intensity calculations based on actual buyer locations

Symbol Legend:

- ✓ = Required verification component
- **-** = Not required for this token type
- **Optional** = Required only when specific enhancements are applied (e.g., when marketplace tokens are also enhanced for LCFS compliance)

Verification Component	Standard QET	CARB Enhanced	Marketplace Dynamic
Base Production CI	✓	✓	✓
Static Transport CI	✓	✓	✓
Dynamic Algorithm	-	✓	✓
CA-GREET Compliance	-	✓	Optional[+]
GIS System Accuracy	-	✓	✓

Verification Component	Standard QET	CARB Enhanced	Marketplace Dynamic
CARB Pathway Validation	-	✓	Optional[+]
LRT-CBTS Integration	-	✓	Optional[+]

[+]Required only when the LCFS enhancement is applied to marketplace transactions

8.1.5 Coordinated Verification Approach

Single Verifier Integration:

When QET-RNG tokens require both marketplace dynamic calculations and LCFS compliance:

- **Unified Verification**: A Single CARB-accredited verification body conducts integrated verification covering all requirements
- **Consolidated Opinion**: Verification statement addresses both QET methodology compliance and LCFS pathway requirements
- **Enhanced Site Visits**: Site visit protocols satisfy QET Section 14, LCFS Section 95500, and dynamic calculation system requirements
- **Comprehensive Documentation**: Single verification report covers all methodology components with appropriate materiality thresholds

8.1.6 Producer Verification Strategy Guidance

Market Participation Decision Matrix:

Option 1: Standard QET-RNG Only

- ISO 14064-3 qualified verifier with RNG experience
- Lower verification costs
- Limited to non-California, non-marketplace transactions

Option 2: Marketplace-Enabled QET-RNG

- Enhanced verifier with dynamic calculation experience
- Moderate verification costs
- Access to the Greentruth marketplace with accurate transport accounting

Option 3: CARB-Ready QET-RNG

- CARB-accredited verifier meeting all requirements
- Higher verification costs
- Maximum market flexibility, including the California LCFS program

Recommendation: Producers uncertain about future market participation should select CARB-accredited verifiers to maintain maximum market flexibility while ensuring dynamic calculation capability for marketplace transactions.

8.2 Materiality Thresholds

Following **QET Section 8.3**:

- Individual batches: 5% materiality threshold
- Portfolio aggregations: 2% materiality threshold

8.3 Verification Opinion

Statements aligned with **QET Sections 8.5 and 11.5**

8.4 Unit Verification Requirements

- All carbon intensity calculations must be verified in $kgCO_2e/MMBtu$ units
- Conversion factors and methodologies must be documented and auditable
- Source data may be collected in various units but final CI reporting must standardize to $kgCO_2e/MMBtu$
- Cross-verification with CA-GREET model outputs required, with unit conversions documented

8.5 LCFS Verification Integration

When QET-RNG tokens are enhanced with LCFS extensions, the verification process must address both methodologies:

Coordinated Verification Approach:

- Single CARB-accredited verification body conducts integrated verification
- Verification opinion covers both QET methodology compliance and LCFS pathway requirements
- Consolidated verification statement addresses materiality for both frameworks
- Site visit protocols must satisfy both QET Section 14 and LCFS Section 95500 requirements

Documentation Requirements:

- CARB pathway validation documentation when applicable
- CA-GREET model compliance verification
- Fuel quality and energy content validation
- Chain of custody verification for environmental attributes

This coordinated approach ensures efficiency while maintaining the integrity requirements of both the QET methodology and LCFS regulations.

9. QET-RNG Data Structure and JSON Schema

Following QET Section 7.

9.1 Key Required Fields

Field	Description	Unit
`tokenAssetType`	"RNG"	-
`energyContent_MMBtu`	1.0 per token	MMBtu
`carbonIntensity_kgCO2e_per_MMBtu`	Facility-specific CI value	$kgCO_2e/MMBtu$
`feedstockType`	LFG, Agricultural, WWTP, etc.	-
`biogasData`	Biogas production and processing details	Various
`processingData`	Energy consumption and efficiency	kWh, MMBtu
`avoidedEmissions_kgCO2e`	Calculated avoided emissions	$kgCO_2e$
`uncertainty`	Combined uncertainty per Section 7	%
`confidenceLevel`	Statistical confidence per Section 7	%
`verification`	Third-party verification information	-
`standards`	Applied methodologies and standards	-

9.2 Complete JSON Example


```
{
 "update": {
   "items": [
     {
       "_id": "QET-RNG-2025-LFG-001",
       "tokenAssetType": "RNG",
```

```
"timeStamps": {
  "periodStart": "2025-01-01T00:00:00Z",
  "periodEnd": "2025-01-31T23:59:59Z"
},
"boundary": {
  "facilityId": "FAC-RNG-LFG-001",
  "gpsLocation": "34.0522°N, 118.2437°W",
  "feedstockType": "Landfill-Gas",
  "segmentType": "RNG-Production"
},
"thermalData": {
  "energyContent_MMBtu": 1.0,
  "netEnergyProduction_MMBtu": 291407,
  "allocationBasis": "energy_content",
  "processingEfficiency": 0.94
},
"biogasData": {
  "rawLFGExtraction_scf": 577363,
  "methaneContent_percent": 50.47,
  "biogasUpgrade_efficiency": 0.96,
  "avoidedEmissions_kgCO2e": 15750642.3,
  "feedstockDiversification": {
    "landfillWaste_percent": 100.0,
    "agriculturalWaste_percent": 0.0,
    "wastewater_percent": 0.0,
    "foodWaste_percent": 0.0
  }
},
"processingData": {
  "electricityConsumption_kWh": 1296000,
  "utilityNG_MMBtu": 0,
  "propaneConsumption_gallons": 0,
  "dieselConsumption_gallons": 0,
  "processingEfficiency": 0.94,
  "fugitiveEmissions_kgCO2e": 1536.45
},
"carbonIntensityData": {
  "baseProductionCI_kgCO2e_per_MMBtu": -65.15,
```

```
        "baseProductionBreakdown": {
          "biogasExtraction_kgCO2e_per_MMBtu": 0.827,
          "gasProcessing_kgCO2e_per_MMBtu": 3.014,
          "gasUpgrading_kgCO2e_per_MMBtu": 2.156,
          "fugitiveEmissions_kgCO2e_per_MMBtu": 5.275,
          "avoidedEmissions_kgCO2e_per_MMBtu": -76.422,
          "baseProductionTotal_kgCO2e_per_MMBtu": -65.15
        },
        "transportCalculationEngine": {
          "algorithm": "GREET_2024_v1.0",
          "verificationDate": "2025-02-14T16:45:22Z",
          "greetDistanceFactor_per_mile_per_MMBtu": 0.004632566667,
          "greetReference": "GREET1_2024_Rev1.xlsm -
    T_D_Flowcharts!AC378",
          "usAveragePipelineDistance_miles": 600,
          "greetTransmissionTotal_kgCO2e_per_MMBtu": 2.78
        },
        "finalCarbonIntensity": {
          "calculationType": "static_bilateral",
          "deliveryEndpoint": "Pacific Gas Pipeline Connection Point
7",
          "transportDistance_miles": 15.5,
          "transportEmissions_kgCO2e_per_MMBtu": 0.072,
          "finalCI_kgCO2e_per_MMBtu": -65.078,
          "calculationTimestamp": "2025-02-15T14:23:56Z"
        }
      },
      "uncertainty": {
        "value": 8.5,
        "uom": "percentage",
        "calculationMethod": "Combined standard deviation and
sampling frequency, see Section 7",
        "components": {
          "measurement": 5.2,
          "temporal": 6.9,
          "parameter": 4.1,
          "model": 3.8
        }
```

```
},
"confidenceLevel": {
  "value": 91.5,
  "uom": "percentage",
  "method": "100% - total combined uncertainty"
},
"verification": {
  "measurer": {
    "id": "MEAS-RNG-001",
    "name": "RNG Analytics Inc."
  },
  "validator": {
    "id": "VAL-RNG-001",
    "name": "Environmental Verification Services"
  },
  "producer": {
    "id": "PROD-RNG-001",
    "name": "RNGA Energy Group LLC"
  },
  "issuance": {
    "timestamp": "2025-02-15T14:23:56Z"
  },
  "statement": {
    "reference": "VER-RNG-2025-001",
    "timestamp": "2025-02-14T16:45:22Z",
    "assuranceLevel": "limited",
    "verificationScope": "cradle-to-gate",
    "materialityThreshold": "5%"
  }
},
"regulatoryCompliance": {
  "epaTier": "Tier-1",
  "carbCompliance": true,
  "rfsPathway": "D5",
  "lcfsCompliance": true,
  "pathwayCode": "LFG-001-CA"
},
"standards": [
```

```
    {
      "standard": {
        "name": "CA-GREET 3.0 Model"
      },
      "carbonIntensity": {
        "value": -64.465,
        "uom": "kgCO2e/MMBtu",
        "factor": "GWP100(AR5)",
        "includesAvoidedEmissions": true
      },
      "scope": "cradle-to-gate",
      "methodology": {
        "type": "Lifecycle_Assessment_with_Avoided_Emissions",
        "avoidedEmissionsIncluded": true,
        "lcaModel": "CA_GREET_3.0",
        "temporalBoundary": "annual",
        "geographicalBoundary": "North_America"
      }
    },
    {
      "standard": {
        "name": "ISO 14064-3"
      }
    },
    {
      "standard": {
        "name": "CARB LCFS"
      }
    },
    {
      "standard": {
        "name": "EPA RFS"
      }
    }
  ],
  "qualityAssurance": {
    "meterCalibration": {
      "lastCalibrationDate": "2025-01-15T00:00:00Z",
```

```
            "calibrationFrequency": "annual",
            "accuracyRating": "±2%"
          },
          "dataValidation": {
            "crossVerification": true,
            "massBalanceReconciliation": true,
            "outlierDetection": "statistical_analysis"
          }
        },
        "attestation": {
          "producerAttestation": {
            "reference": "PA-RNG-2025-001",
            "timestamp": "2025-01-31T23:59:59Z",
            "doubleCountingPrevention": true,
            "environmentalAttributeTransfer": true
          },
          "chainOfCustody": {
            "purchaseOrderReference": "PO-RNG-2025-001",
            "conveyanceAffidavit": "CA-RNG-2025-001",
            "titleTransferComplete": true
          }
        }
      }
    ]
  }
}
```

9.3 Schema Validation Requirements

All QET-RNG tokens must conform to the complete schema structure with the following mandatory validations:

- **Unit Consistency**: All carbon intensity values must be expressed in $kgCO_2e/MMBtu$
- **Energy Content**: Fixed at 1.0 MMBtu per token
- **Uncertainty Reporting**: Combined uncertainty must be calculated and reported per Section 7
- **Verification Documentation**: Complete verification chain must be documented
- **Regulatory Compliance**: Applicable regulatory pathways must be identified and documented

- **Avoided Emissions**: Calculation methodology and values must be transparent and auditable

Schema Enforcement: The EarnDLT blockchain registry automatically validates all required fields before token issuance, ensuring data integrity and completeness.

9.3.1 LCFS Enhancement Compatibility

QET-RNG tokens are designed for seamless enhancement with LCFS extensions:

- **Modular Architecture**: Core RNG data structure remains intact during LCFS enhancement
- **Conditional Validation**: LCFS fields are validated only when enhancement is applied
- **API Integration**: Standard QET-RNG tokens can be enhanced via PATCH operations
- **Backward Compatibility**: Enhanced tokens maintain all original RNG-specific data

Enhancement Reference: See *Methodology for the Production and Verification of Low Carbon Fuel Standard Quantified Emissions Tokens® (QET-LCFS)* Section 10.3 for detailed enhancement procedures.

9.4 Dynamic Carbon Intensity Schema Examples

9.4.1 GreenTruth Marketplace Transaction Example

For tokens sold through GreenTruth marketplace with dynamic transport calculation:


```
{
  "carbonIntensityData": {
    "baseProductionCI_kgCO2e_per_MMBtu": -65.15,
    "baseProductionBreakdown": {
      "biogasExtraction_kgCO2e_per_MMBtu": 0.827,
      "gasProcessing_kgCO2e_per_MMBtu": 3.014,
      "gasUpgrading_kgCO2e_per_MMBtu": 2.156,
      "fugitiveEmissions_kgCO2e_per_MMBtu": 5.275,
      "avoidedEmissions_kgCO2e_per_MMBtu": -76.422,
      "baseProductionTotal_kgCO2e_per_MMBtu": -65.15
    },
```

```
    "transportCalculationEngine": {
      "algorithm": "GREET_2024_v1.0",
      "verificationDate": "2025-02-14T16:45:22Z",
      "greetDistanceFactor_per_mile_per_MMBtu": 0.004632566667,
      "greetReference": "GREET1_2024_Rev1.xlsm - T_D_Flowcharts!AC378"
    },
    "finalCarbonIntensity": {
      "calculationType": "dynamic_marketplace",
      "buyerLocation": "Denver, CO Distribution Hub",
      "transportDistance_miles": 847.3,
      "transportEmissions_kgCO2e_per_MMBtu": 3.925,
      "finalCI_kgCO2e_per_MMBtu": -61.225,
      "calculationTimestamp": "2025-03-15T10:23:17Z",
      "greenTruthOrderId": "GT-2025-RNG-001",
      "qualityControlStatus": "passed",
      "calculationAccuracy": "±2.1%"
    }
  }
}
```


9.4.2 Bilateral Transaction Example

For direct bilateral transactions with known delivery endpoint:


```
{
  "carbonIntensityData": {
    "baseProductionCI_kgCO2e_per_MMBtu": -65.15,
    "baseProductionBreakdown": {
      "biogasExtraction_kgCO2e_per_MMBtu": 0.827,
```

```
      "gasProcessing_kgCO2e_per_MMBtu": 3.014,
      "gasUpgrading_kgCO2e_per_MMBtu": 2.156,
      "fugitiveEmissions_kgCO2e_per_MMBtu": 5.275,
      "avoidedEmissions_kgCO2e_per_MMBtu": -76.422,
      "baseProductionTotal_kgCO2e_per_MMBtu": -65.15
    },
    "transportCalculationEngine": {
      "algorithm": "GREET_2024_v1.0",
      "verificationDate": "2025-02-14T16:45:22Z",
      "greetDistanceFactor_per_mile_per_MMBtu": 0.004632566667,
      "greetReference": "GREET1_2024_Rev1.xlsm - T_D_Flowcharts!AC378"
    },
    "finalCarbonIntensity": {
      "calculationType": "static_bilateral",
      "deliveryEndpoint": "Pacific Gas Pipeline Connection Point 7",
      "transportDistance_miles": 15.5,
      "transportEmissions_kgCO2e_per_MMBtu": 0.072,
      "finalCI_kgCO2e_per_MMBtu": -65.078,
      "calculationTimestamp": "2025-02-15T14:23:56Z"
    }
  }
}
```


9.4.3 Schema Validation Requirements

All QET-RNG tokens must conform to the following validation requirements:

- Base Production CI: Must be calculated and verified annually
- Transport Calculation Engine: Algorithm must be verified annually for accuracy
- Final CI Calculation: Must include a complete audit trail and timestamps
- Dynamic Calculations: Must pass real-time quality control validation

- Static Calculations: Must be verified at time of token issuance

10. Documentation and Attestation Requirements

10.1 Producer Attestation

Required monthly attestations from facility operators must be recorded in the `attestation.producerAttestation` section of the JSON schema, confirming:

- Biogas production volumes and environmental attributes transfer
- No double-counting or double-selling of environmental benefits
- Compliance with renewable fuel standards
- Complete environmental attribute transfer as documented in purchase orders and conveyance affidavits

10.2 Chain of Custody Documentation

Producer Responsibilities (Universal Requirements):

RNG facility operators must maintain and provide the following documentation to support QET-RNG issuance:

- Producer attestations confirming environmental benefit ownership and transfer rights
- Legal conveyance documentation establishing clear title transfer to EarnDLT registry
- Third-party verification reports validating production and environmental claims
- Compliance documentation for applicable renewable energy certificate standards
- Facility operational records (gas meter readings, composition analysis, etc.)

Transaction-Specific Documentation:

Bilateral Transactions:

- Producer-generated purchase orders specifying environmental attributes and transfer rights
- Custom conveyance affidavits between parties
- Direct buyer-seller correspondence and agreements

GreenTruth Marketplace Transactions:

- System-generated purchase orders automatically created upon marketplace transaction completion
- Automated conveyance documentation produced by GreenTruth platform
- Digital marketplace transaction records with cryptographic signatures

- Automated environmental attribute transfer confirmations

EarnDLT Registry Services:

The EarnDLT blockchain registry automatically captures and preserves chain of custody information through:

- Immutable recording of all documentation references in token JSON structure
- Cryptographic timestamping of ownership transfers (both bilateral and marketplace)
- Automated validation of completeness before token issuance
- Permanent audit trail maintenance through blockchain architecture
- Integration with GreenTruth marketplace transaction data

10.2.1 GreenTruth Marketplace Dynamic CI Integration

Automated Carbon Intensity Calculation Process:

Step 1: Order Placement

- Buyer places order specifying delivery location
- GreenTruth system calculates delivery distance using verified GIS algorithms
- Dynamic transport emissions calculated using verified emission factors
- Final carbon intensity calculated and displayed to buyer before order confirmation

Step 2: Order Confirmation

- Final carbon intensity locked in upon buyer confirmation
- Transport calculation metadata permanently recorded on EarnDLT blockchain
- Quality control verification of calculation accuracy performed automatically

Step 3: Token Transfer

- Updated JSON schema with final carbon intensity applied to transferred tokens
- Complete audit trail of calculation process recorded
- Exception reports generated for any calculation anomalies

Generated Documentation:

- **Dynamic CI Calculation Records**: Complete calculation trail including distance, emission factors, and final CI
- **Quality Control Reports**: Automated validation of calculation accuracy and data integrity
- **Algorithm Application Logs**: Detailed records of dynamic calculation engine usage
- **Exception Reports**: Documentation of any calculation errors or data anomalies

Verification Trail Maintenance:

- All dynamic calculations linked to verified annual algorithm validation
- Real-time monitoring of calculation accuracy and system performance
- Automated alerts for calculation deviations exceeding acceptable thresholds
- Complete blockchain documentation of all dynamic calculation events

10.3 Record Retention

Following industry-standard environmental certificate management practices:

- Minimum 7-year retention period aligned with regulatory requirements
- Digital and physical documentation standards per ISO 14064-3
- Comprehensive audit trail maintenance and immutable record-keeping
- Chain of custody documentation preservation

11. Integration with Existing Systems

11.1 EarnDLT Blockchain Registry

QET-RNG certificates are issued, managed, and tracked exclusively on the EarnDLT blockchain-based registry, providing:

- Immutable token issuance and lifecycle management
- Transparent ownership and transfer history
- Cryptographically secured chain of custody documentation
- Public transparency and auditability through blockchain verification
- Optional export capabilities for customers requiring external registry placement

11.2 RNG Market Integration

Designed for compatibility with:

- California LCFS program requirements
- Federal RFS pathways
- Voluntary carbon markets
- Corporate sustainability reporting

11.2.1 California LCFS Market Integration

For RNG producers seeking to generate LCFS credits in California markets, QET-RNG tokens **must be enhanced** with the QET-LCFS extension methodology to ensure full regulatory compliance:

- **CARB Pathway Certification**: All California sales require certified CARB pathway codes

- **QET-LCFS Enhancement**: Standard QET-RNG tokens must be upgraded using the QET-LCFS extension methodology
- **Dual Verification**: CARB-accredited verifiers must validate LCFS-specific compliance elements
- **LRT-CBTS Integration**: Enhanced tokens enable direct integration with CARB's reporting systems

Mandatory Enhancement Process: Producers intending to sell RNG tokens for LCFS compliance must follow the enhancement procedures outlined in the *Methodology for the Production and Verification of Low Carbon Fuel Standard Quantified Emissions Tokens® (QET-LCFS)*.

11.3 Optional External Registry Transfer

While QET-RNG certificates are natively issued and managed on the EarnDLT blockchain registry, optional transfer capabilities are available when beneficial to users:

- **Export Functionality**: Standardized data export formats compatible with major environmental certificate registries.
- **Customer Choice**: Users may request certificate transfer to external registries for specific market requirements.
- **Data Integrity**: All transfers maintain complete audit trail and verification documentation.
- **Compliance Mapping**: Automated mapping to different regulatory and voluntary market standards are available when exporting certificates.

11.4 Blockchain Registry Advantages

The EarnDLT blockchain-based registry provides unique advantages over traditional registry systems:

- **Immutable Records**: Cryptographic assurance prevents certificate tampering or double-counting
- **Real-time Transparency:** All stakeholders can verify certificate authenticity and ownership history
- **Reduced Counterparty Risk**: Decentralized architecture eliminates single points of failure
- **Cost Efficiency:** Automated smart contracts reduce administrative overhead and transaction costs
- **Global Accessibility**: 24/7 availability without geographic restrictions or business hour limitations

11.5 LCFS Extension Requirement

Mandatory Enhancement for California Markets: Any QET-RNG token intended for sale into California's LCFS program must be enhanced with QET-LCFS extensions prior to credit generation. This ensures:

- CARB pathway certification compliance
- LRT-CBTS reporting system integration
- Proper carbon intensity unit conversion
- CARB-accredited verification requirements

The enhancement process does not modify the underlying RNG thermal certificate data but adds the necessary LCFS-specific compliance fields required for California market participation.

12. Quality Assurance and Control

12.1 Measurement Quality

All measurement and verification protocols must be documented in the `qualityAssurance` section of the token JSON structure, including:

- Meter calibration requirements per ASTM and API standards
- Minimum detection limits for composition analysis consistent with EPA methods
- Regular third-party auditing of measurement systems
- Measurement uncertainty quantification and reporting per Section 7 requirements

12.2 Data Validation

- Cross-verification with utility records and regulatory filings
- Mass balance reconciliation using engineering principles
- Statistical outlier detection and correction protocols
- Independent data verification through multiple sources

12.3 Registry Integration Quality Controls

- Automated data validation prior to certificate issuance
- Cross-reference verification with multiple tracking systems
- Duplicate certificate prevention through blockchain-based immutable records
- Real-time monitoring of certificate lifecycle status

12.4 Dynamic Calculation Quality Assurance

Algorithm Accuracy Requirements:

- Distance calculation accuracy: ±2% maximum deviation from verified measurements
- GREET factor application: 100% consistency with verified GREET model parameters
- Calculation completion time: <30 seconds for all marketplace transactions
- System availability: 99.9% uptime requirement for the dynamic calculation engine

Quality Control Monitoring:

- Real-time validation of all dynamic calculations against GREET-verified parameters
- Automated detection of calculation anomalies exceeding acceptable thresholds
- Daily reconciliation of dynamic calculations with GREET baseline parameters
- Monthly statistical analysis of calculation accuracy and system performance

Exception Handling Procedures:

- Automatic system failover to conservative GREET-based transport emission estimates
- Manual calculation backup procedures using verified GREET factors
- Immediate notification protocols for calculation accuracy deviations
- Complete documentation of all exceptions and resolution procedures

Audit Trail Requirements:

- Permanent blockchain recording of all GREET-based calculation events
- Immutable documentation of the GREET algorithm application and parameters used
- Complete traceability from buyer location to final carbon intensity using GREET factors
- Annual verification of audit trail completeness and GREET model alignment