1.2
version

Methodology for the Production and Verification of Solid Fuel Thermal Quantified Emissions Tokens (QET-SOL) — kgCO$_2$e/MMBtu

This methodology defines procedures for producing, quantifying, disclosing, and verifying QET-SOL, with GHG intensity standardized to kgCO$_2$e/MMBtu. It enables QET-SOL to function as audit-ready environmental attribute certificates aligned with ISO 14064-3 and referencing the EarnDLT QET core methodology.

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Methodology for the Production and Verification of Solid Fuel Thermal Quantified Emissions Tokens (QET-SOL) — kgCO$_2$e/MMBtu

Executive Summary

This methodology details the production, quantification, disclosure, uncertainty reporting, and third-party verification of Solid Fuel Thermal Quantified Emissions Tokens® (QET-SOL), ensuring all greenhouse gas (GHG) intensities are standardized to **kgCO$_2$e/MMBtu**. It formalizes procedures so that QET-SOLs serve as precise, audit-friendly environmental attribute certificates, fully aligned with ISO 14064-3 and directly referencing the EarnDLT QET core methodology.

1. Introduction and Scope

Purpose: Provide a complete framework for creating QET-SOLs with verified negative carbon intensity (CI), each representing 1MMBtu of solid fuel energy. Designed so customers can offset both Scope 1 and Scope 3 emissions from natural gas, LNG, hydrogen, or similar products by pairing their positive-CI QETs with QET-SOLs.

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)
- **GREET Model 2023**
- **ISO 14067:2018**
- **GHG Protocol Corporate Standard**
- **EPA Renewable Fuel Standard**
- **EarnDLT Protocol**

3. Terms and Definitions

- **QET-SOL (Solid Fuel Thermal QET)**: Digital token for 1MMBtu of thermal energy from solid fuel with verified negative CI in $kgCO_2e$/MMBtu.
- **Negative Carbon Intensity (NCI)**: Net negative CI per MMBtu (e.g., $-116.39 kgCO_2e$/MMBtu).
- **Co-Product Allocation**: Distribution of process emissions (see QET Section 5.7.4).
- **Avoided Emissions Credit**: GHG reductions from landfill diversion, detailed in calculation steps below.
- **Uncertainty**: As per QET Section 6, parameter describing possible dispersion in quantification results.

4. System Boundaries and Scope

4.1 Boundary Definition
Matches **QET Section 4.4**:

- *Upstream***:** Feedstock sourcing, transport, prep.
- *Core***:** Solid fuel and co-product generation, on-site energy/process inputs, allocations.
- *Downstream***:** Avoided landfill emissions, credit assignment.

4.2 Exclusions
End-use combustion[1] is outside QET-SOL CI; see **QET Section 4.4.2**.

5. Quantification Methodology

5.1 Calculation Framework
As per **QET Section 5**:

$$QET\text{-}T\ CI(kgCO_2e/MMBtu) = \frac{(Total\ Process\ Emissions\ x\ Solid\ Fuel\ Allocation\ Factor) - Avoided\ Emissions\ Credit}{Net\ Solid\ Fuel\ Energy\ Production\ (MMBtu)}$$

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

5.2 Calculation Steps

- **Step 1: Total Process Emissions ($kgCO_2e$)**
  $$Total\ Process\ Emissions = Electricity\ Emissions + Utility\ NG\ Emissions + Fugitive\ Emissions$$

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[1] End-use combustion emissions are excluded from QET-SOL carbon intensity calculations per QET Section 4.4.2, establishing clear boundary definitions between upstream producer responsibilities (included in CI) and downstream consumer combustion emissions (excluded from CI but offset through negative CI credits). See 4.2 Combustion Emissions Exemption for detailed boundary rationale and practical applications.

(Conversion factors: **QET Section 5.3, 5.5**)

- **Step 2: Co-Product Allocation Factor**

$$Solid\ Fuel\ Allocation\ Factor\ =\ \frac{Solid\ Fuel\ Energy\ (MMBtu)}{Solid\ Fuel\ Energy + Biogas\ Energy\ (MMBtu)}$$

(See **QET Section 5.7.2**)

- **Step 3: Avoided Emissions Credit**
  Calculated using GREET waste factors:

$$Total\ Credit = \Sigma(Feedstock\ Mass\ \times\ Avoidance\ Factor \times Treatment\ Factor)$$

- **Step 4: Net Energy Production**

$$Net\ Solid\ Fuel\ Energy\ (MMBtu) = Solid\ Fuel\ Produced\ (tons)\ \times$$
$$Energy\ Density\ (MMBtu/ton)\ \times\ Moisture\ Correction\ Factor$$

5.3 Example Calculation
(Based on Burcell GREET case)

Variable	Value
Total Process Emissions	3,997,000kgCO$_2$e/yr
Solid Fuel Allocation	0.996
Allocated Emissions	3,981,000kgCO$_2$e/yr
Avoided Emissions Credit	19,801,000kgCO$_2$e/yr
Net Solid Fuel Energy	135,787.5MMBtu/yr

$$QET\text{-}T\ CI\ =\ \frac{3,981,000 - 19,801,000}{135,787.5}\ =\ -116.39kgCO_2e/MMBtu$$

6. Data Requirements

(per QET Section 5.1.1)

- Feedstock types/amounts/properties (mass, moisture, LHV)
- Process inputs: electricity (kWh), natural gas (MMBtu)
- Produced biogas (MMBtu)
- Emission factors, GWPs, allocation formulas
- Full evidence documentation (**QET Section 8.1**)

7. Uncertainty Reporting Requirements

(Expanded: Directly Reference QET Section 6)

Uncertainty assessment is integral, providing confidence in CI results, fully aligned with ISO 14064-3 and QET Section 6.

7.1 Sources of Uncertainty

- **Parameter Uncertainty**: Emission/conversion factors, input accuracy
- **Scenario Uncertainty**: Waste futures, end-of-life scenarios
- **Model Uncertainty**: LCA/allocations, GREET limitations
- **Measurement Uncertainty**: Equipment, calibration, MDL
- **Temporal Uncertainty**: Sampling frequency, representativeness

7.2 Quantification and Calculation

- **Total Uncertainty (U)**:

$$U = \frac{\sigma}{\sqrt{n}}$$

  where σ is the standard deviation, n is the number of measurements (**QET Section 6.2**)

- **Temporal Uncertainty (MdAPE)**:

$$MdAPE = median\left(\frac{|yi - \widehat{yi}|}{yi}\right)$$

  Where yi= actual annual average, $\widehat{yi}$= measured annual average, and $i \in$ [1, 1000]

- **Typical MdAPE Values for 5kg/hr MDL:**

  - Annual: 95.5%
  - Monthly: 84.8%
  - Weekly: 52.4%
  - Daily: 25.9%
  - Hourly: 8.6%

7.3 Combining and Reporting Uncertainty

- **Combined Uncertainty:**

$$U_{total} = \sqrt{U_1^2 + U_2^2 + ... + U_n^2}$$

where each U_i is a percentage from an independent source (**QET Section 6.4**)

- **Target**: Not to exceed ±10% of the mean for QET-SOL batches; if exceeded, increase frequency or precision
- **Confidence Level**: Calculated as $100\% - U$ (**QET Section 6.3**)

7.4 Disclosure

All QET-SOLs must report:

- Components of uncertainty (measurement, temporal, allocation, etc.)
- Combined uncertainty as a percentage of mean CI
- Confidence level
- Calculation method and references to QET Section 6

Sample JSON Fields

json
```json
"uncertainty": {
  "value": 8.5,
  "uom": "percentage",
  "calculationMethod": "Combined standard deviation and sampling
frequency, see Section 7",
  "components": {
    "measurement": 5.2,
    "temporal": 6.9
  }
},
"confidenceLevel": {
  "value": 91.5,
  "uom": "percentage",
  "method": "100% - total combined uncertainty"
}
```

Note:
All QET-SOLs must quantify and report uncertainty using the above formulas and requirements,

with step-by-step guides referencing Section 7 of this document and Section 6 of the QET core methodology.

8. Verification Requirements

Aligned with **QET Section 8**:

- Third-party audit by a verifier experienced with GREET, LCA, and waste-to-energy.
- Field audit, data trail, and documentation per **QET Section 14.**
- Materiality threshold: 5% for batches, 2% for portfolios (**QET Section 8.3**).
- Verification statements aligned with **QET Sections 8.5, 11.5.**

9. QET-SOL Data Structure & JSON Specification

Follow **QET Section 7**.

9.1 Key Required Fields

Field	Description	UOM
tokenAssetType	SolidFuel	
energyContent_MMBtu	1.0 per token	MMBtu
carbonIntensity_kgCO2e_per_MMBtu	Facility value (negative)	kgCO$_2$e/MMBtu
allocationBasis	"energy_content"	
feedstockData	Input waste stream breakdown	tons, etc.
processData	Electricity, NG, fugitive emissions	kWh, MMBtu, kg
avoidedEmissions_kgCO2e	For period/facility	kgCO$_2$e
uncertainty	Per Section 7	%
confidenceLevel	Per Section 7	%
verification	Issuer, validator, statement, audit info	

standards	Standards/methodologies used	

9.2 JSON Example

json

```json
{
  "update": {
    "items": [
      {
        "_id": "QET-SOL-2025-SF-001",
        "tokenAssetType": "SolidFuel",
        "timeStamps": {
          "periodStart": "2025-01-01T00:00:00Z",
          "periodEnd": "2025-01-31T23:59:59Z"
        },
        "boundary": {
          "facilityId": "FAC-SOLIDFUEL-001",
          "gpsLocation": "32.6526°N, 83.7159°W",
          "feedstockType": "MSW-Organic",
          "segmentType": "SolidFuel-Production"
        },
        "thermalData": {
          "energyContent_MMBtu": 1.0,
          "carbonIntensity_kgCO2e_per_MMBtu": -116.39,
          "netEnergyProduction_MMBtu": 135787.5,
          "allocationBasis": "energy_content",
          "coProductAllocationFactor": 0.996
        },
        "feedstockData": {
          "paperCardboard_tons": 10650.0,
          "foodWaste_tons": 3550.0,
          "yardWaste_tons": 3550.0,
          "totalOrganicFeedstock_tons": 21300.0,
          "avoidedEmissions_kgCO2e": 19800753.95
        },
        "processData": {
          "electricityConsumption_kWh": 1988000,
```

```json
        "utilityNG_MMBtu": 43332.44,
        "coProductBiogas_MMBtu": 547.5,
        "processingEfficiency": 0.943
      },
      "uncertainty": {
        "value": 8.5,
        "uom": "percentage",
        "calculationMethod": "Combined standard deviation and
sampling frequency, see Section 7",
        "components": {
          "measurement": 5.2,
          "temporal": 6.9
        }
      },
      "confidenceLevel": {
        "value": 91.5,
        "uom": "percentage",
        "method": "100% - total combined uncertainty"
      },
      "verification": {
        "measurer": {"id": "MEAS-QET-SOL-001", "name": "Solid Fuel
Analytics Inc."},
        "validator": {"id": "VAL-QET-SOL-001", "name": "LCA
Verification Services"},
        "producer": {"id": "PROD-QET-SOL-001", "name": "Sustainable
Fuels Corp"},
        "issuance": {"timestamp": "2025-02-15T14:23:56Z"},
        "statement": {
          "reference": "VER-QET-SOL-2025-001",
          "timestamp": "2025-02-14T16:45:22Z",
          "assuranceLevel": "limited"
        }
      },
      "standards": [
        {
          "standard": {"name": "GREET LCA 2023"},
```

```
            "carbonIntensity": {"value": -116.39, "uom":
"kgCO2e/MMBtu", "factor": "GWP100(AR5)", "includesAvoidedEmissions":
true},
            "scope": "cradle-to-gate",
            "methodology": {
              "type": "Lifecycle_Assessment_with_Avoided_Emissions",
              "avoidedEmissionsIncluded": true,
              "lcaModel": "GREET_2023"
            }
          },
          {"standard": {"name": "ISO 14064-3"}}
        ]
      }
    ]
  }
}
```

All carbon intensity and emissions values must be expressed in **kgCO$_2$e/MMBtu**.

10. Lifecycle Management and Claims

- Follow the protocols for token issuance, audit trails, transfers, and retirement as outlined in **QET Sections 9 and 10**.
- Claims must reference kgCO$_2$e/MMBtu value and include verification and uncertainty (confidence) details (**QET Sections 8.5, 11.5**).

11. Implementation Notes

All procedures, formulae, templates, data structures, and documentation requirements are faithfully aligned with the EarnDLT QET core methodology and ISO 14064-3 best practices. Uncertainty is elevated as a mandatory reporting field, and confidence levels are to be calculated transparently per the formulas described.

References to QET Methodology:

- System Boundaries: Section 4.4
- Quantification Methodology & Formula: Section 5, 5.5
- Data Requirements: Section 5.1.1
- Uncertainty & Confidence: Section 6
- Verification, Materiality, and Audit: Section 8, 8.3

- Claims & Lifecycle: Sections 9, 10
- Assurance/Confidence: Sections 6.3, 8.4, 8.5, 11.5

Document Footnote:
This methodology is a supplement to and must be implemented in conjunction with the EarnDLT QET methodology "*Methodology for the Production and Verification of Quantified Emissions Tokens (QETs) in Accordance with ISO 14064-3*", incorporating core uncertainty reporting protocols by explicit citation and cross-reference.