MEROS

Methane & Emission Reduction Opportunity Study

Methodology Specification

Version 2.0 | Draft for Peer Review

2025

Patent pending in the United Kingdom.

Supersedes: MEROS Methodology Specification v1.0

Version 2.0 additions indicated throughout

What is new in Version 2.0

Version 2.0 adds the following to the v1.0 specification:

- Section 3.15–3.20: Six new terms and definitions
- Section 4.7–4.8: Two new methodology principles — Baseline Documentation Primacy and Evidence Chain Integrity
- Section 5.7: WCN Driver Classification — Rate-driven vs Intensity-driven streams
- Section 5.8: Combined DEEI Score for node sequencing
- Section 12.5: MEROS Projects — MAC curve, project portfolio, business case framework
- Section 12.6: MEROS Verified — pre/post measurement and independent verification framework
- Section 14: MEROS Periodic Table Register — visual baseline documentation standard
- Annex B: Updated — seven new abbreviations added
- Annex D: New — MEROS Projects Methodology
- Annex E: New — MEROS Verified Framework

Foreword

The oil and gas industry spends significant resources detecting and quantifying methane and carbon dioxide emissions using satellite surveillance, aerial surveys, continuous sensor networks, and manual inspection programmes. The predominant paradigm is reactive: emissions are sought after a facility is built and operating, found through measurement, and then addressed through corrective action. This approach has produced real reductions, but it misses the most consequential intervention point — the design stage, when emission sources are created or could be prevented at minimal cost.

MEROS — the Methane and Emission Reduction Opportunity Study — is a structured, facilitated methodology that addresses this gap. It applies a systematic, guideword-based approach to identify emission sources, classify their causes, and generate remediation opportunities, anchored in the plant's engineering design basis rather than in operational measurement. Its pre-work tools derive quantitative priority intelligence from the Heat and Mass Balance, so that a multi-discipline team arrives at a MEROS workshop already knowing which systems carry the greatest emission risk. The team's time is therefore concentrated on the highest-consequence nodes, and the output is a ranked, assigned, and traceable action register — not a general recommendations log.

The methodology is deliberately modelled on the Hazard and Operability Study (HAZOP) technique, drawing on the institutional familiarity, discipline, and close-out rigour that HAZOP has established over fifty years of practice. The intent is that MEROS should sit alongside HAZOP in project schedules, be recognised by regulators as a systematic emission management evidence trail, and be maintained as a living document throughout the operating life of a facility.

Version 2.0 of this specification extends the v1.0 framework in three significant directions: it introduces a formal MEROS Projects layer that translates the de-carbonisation opportunity register into a sanctionable project portfolio with marginal abatement cost analysis; it defines the MEROS Verified framework for independent pre/post measurement and verification of emission reductions; and it establishes the MEROS Periodic Table Register as a standardised visual baseline documentation format. Together these additions complete the evidence chain from design-basis identification through to independently verified reduction — the full lifecycle of a methane and carbon management programme grounded in engineering design data.

This document constitutes the second published specification of the MEROS methodology, submitted for peer review by the academic and standards community. Feedback and commentary from independent experts are invited to strengthen and validate the approach prior to formal standardisation.

1 Scope

This document specifies the MEROS methodology for the systematic identification, classification, and reduction of hydrocarbon emissions from oil and gas processing facilities. It defines the purpose, principles, pre-work requirements, workshop process, guideword set, documentation requirements, deliverables, lifecycle maintenance obligations, project portfolio development, emission reduction verification, and visual baseline documentation associated with a MEROS study.

MEROS is applicable to:

- New facilities at the Front End Engineering and Design (FEED) stage, where the Heat and Mass Balance (HMB) is available and major design decisions remain open;
- Existing operational facilities undergoing a systematic emission reduction review;
- Facilities subject to a Management of Change (MoC) process where the change has the potential to create new emission sources or materially alter existing ones;
- Post-project verification of emission reductions achieved through implementation of de-carbonisation opportunities identified in a prior MEROS study.

MEROS is not applicable to:

- Facilities for which no Heat and Mass Balance or equivalent process simulation data exists;
- Non-hydrocarbon processing facilities where the release taxonomy defined in this document does not apply;
- Emergency or incident response activities.

NOTE: *This document does not cover the detailed engineering calculations underpinning the pre-work tools MethaneScan and FlareCO2Scan. Those tools are specified separately and are open-source implementations of the pre-work methodology described in Section 5.*

2 Normative References

The following documents, in whole or in part, are referenced in this specification and are indispensable for its application.

- IEC 61882:2016, Hazard and operability studies (HAZOP studies) — Application guide
- ISO 14064-1:2018, Greenhouse gases — Part 1: Specification with guidance at the organisation level for quantification and reporting of greenhouse gas emissions and removals
- ISO 14064-3:2019, Greenhouse gases — Part 3: Specification with guidance for the verification and validation of greenhouse gas statements
- API RP 754:2016, Process Safety Performance Indicators for the Refining and Petrochemical Industries
- EPA 40 CFR Part 98 Subpart W: Petroleum and Natural Gas Systems (GHGRP)
- EU Regulation 2024/1787 on the reduction of methane emissions in the energy sector
- OGMP 2.0 Technical Guidance Document: Satellite, Aerial and Ground-based Detection, Carbon Mapper, 2023
- IEA Global Methane Tracker 2025, International Energy Agency
- CCAC Oil and Gas Methane Partnership 2.0 Technical Guidance: Fugitive Emissions
- EPA AP-42: Compilation of Air Emissions Factors — Chapter 5: Petroleum Industry

NEW IN v2.0: *ISO 14064-3:2019 and EPA AP-42 added in v2.0 to support the MEROS Verified framework (Section 12.6) and MEROS Projects quantification methodology (Annex D).*

3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1 MEROS study

A structured, facilitated, multi-discipline review of a hydrocarbon processing system, conducted using the MEROS methodology to identify emission sources, classify root causes, and generate ranked reduction opportunities. The term 'MEROS study' refers to the complete process from pre-work through action close-out.

3.2 Heat and Mass Balance (HMB)

A process engineering document, typically produced by steady-state simulation software, that specifies the thermodynamic state (temperature, pressure, vapour fraction, molar composition, and flow rate) of every process stream in a facility. The HMB constitutes the primary design-basis input to the MEROS pre-work phase.

3.3 SBEM hierarchy

The System-Based Emission Management five-level classification hierarchy used to structure MEROS studies. Levels are: L1 Stream, L2 Equipment, L3 System, L4 Unit, L5 Train. All MEROS analysis is conducted at L3 (System) level, with results aggregated to L4 and L5.

3.4 MEROS node

The unit of analysis in a MEROS study, corresponding to L3 (System) in the SBEM hierarchy. Each node is a functional grouping of equipment performing a single process duty. Nodes are analogous to HAZOP nodes but defined by emission relevance rather than by pressure boundary.

3.5 Weighted Methane Number (WMN)

A dimensionless relative score quantifying the equivalent methane leak rate of a process stream through a standardised 1 mm^2 orifice, calculated using choked-flow orifice equations for gas-phase streams and the Bernoulli equation for liquid-phase streams. The WMN is the primary metric of the MethaneScan pre-work tool and determines stream-level fugitive emission priority.

3.6 Weighted Carbon Number (WCN)

A metric quantifying the CO_2 emission consequence of a process stream in two complementary dimensions: (a) Intensity — kilograms of CO_2 produced per standard cubic metre of vapour flared, derived from stream composition by complete combustion stoichiometry; and (b) Rate — tonnes of CO_2 per hour produced if the entire vapour stream is routed to flare under a blocked-discharge scenario. The WCN is the primary metric of the FlareCO2Scan pre-work tool and determines stream-level flaring CO_2 priority.

3.7 Priority tier

A classification assigned to each MEROS node based on aggregated WMN and WCN scores. Four active tiers are defined: Very High (VH), High (H), Medium (M), and Low (L). Nodes may additionally be classified as Out of Scope (OOS) where the stream carries zero methane and zero combustible content. Tier assignment is described in Section 5.

3.8 Release point

A specific item of equipment, instrument, or physical connection within a MEROS node from which an emission can originate. Each release point is individually assessed during the MEROS workshop. Release points are analogous to HAZOP deviations but represent physical sources rather than process conditions.

3.9 Release type

A classification of the emission mechanism by which a hydrocarbon release enters the atmosphere. Seven release types are defined in this specification: Flaring (F), Venting (V), Fugitive Emission (FE), Open Burning (OB), Engine Burning (EB), Fuel Burning (FB), and Other Release (OR).

3.10 Root cause

The underlying condition or event that causes a release to occur at a given release point. Multiple root causes may apply to a single release point. A standard taxonomy of root causes is defined in Section 7.

3.11 SCAMPERO

The structured guideword set used in MEROS to systematically explore remediation options for each release point. SCAMPERO is an acronym for: Substitute, Combine, Adapt, Modify, Put to other use, Eliminate, Reverse, Others.

3.12 De-carbonisation opportunity

A remediation action identified through the SCAMPERO guideword process that has the potential to reduce or eliminate an emission and that is technically and economically feasible within the operating or design context of the facility. Opportunities are rated by Impact (High, Medium, Small) and Doability (Very Difficult, Difficult, Easy).

3.13 MEROS leader

The qualified facilitator who leads the MEROS workshop. The MEROS leader must hold relevant process engineering competence and must be independent of the design team for the system under review. Qualifications are specified in Section 8.

3.14 Evergreen maintenance

The obligation to update and revalidate a MEROS study at defined intervals and in response to Management of Change events, ensuring the study remains current and reflective of actual plant configuration. Requirements are specified in Section 11.

> **NEW IN v2.0:** *Terms 3.15 through 3.20 are new additions in Version 2.0.*

3.15 WCN driver classification

A sub-classification of the Weighted Carbon Number that identifies the primary dimension driving a stream's WCN tier assignment. A stream is classified as Rate-driven (R) when its WCN Rate percentage exceeds its WCN Intensity percentage relative to the facility peak, indicating that the volume of vapour flow under blocked-discharge conditions is the dominant risk factor. A stream is classified as Intensity-driven (I) when its WCN Intensity percentage exceeds its WCN Rate percentage, indicating that the heavy hydrocarbon composition of the stream is the dominant risk factor. The driver classification determines the appropriate engineering response: Rate-driven streams require flow-reduction interventions (flare gas recovery compressors, ESD philosophy review, blowdown sequencing); Intensity-driven streams require composition-based interventions (vapour recovery units, stream rerouting, combustion efficiency improvement).

3.16 Design-Basis Emission and Energy Indicators (DEEI)

The family of three standardised, HMB-derived stream-level scores used in the MEROS pre-work phase: the Weighted Methane Number (WMN), the Weighted Carbon Number (WCN), and the Weighted Energy Number (WEN, specified separately). All three metrics share the same calculation philosophy: a standardised reference condition applied to every stream, producing a relative score normalised to the facility peak, assigned to a tier by percentage threshold. The DEEI family provides a consistent, comparable basis for emission and energy priority assessment across all facility types.

3.17 MEROS Periodic Table Register

A standardised visual representation of the MEROS priority register in which every stream of a facility is displayed as an element in a grid structured analogously to the periodic table of elements. Stream elements are arranged left-to-right in decreasing order of combined WMN/WCN score (Very High to Low), and top-to-bottom by process section (SBEM L4 Unit). Streams formally excluded from LDAR scope (Out of Scope) are displayed in a separate island below the main table, analogous to the lanthanide and actinide series in the periodic table. The MEROS Periodic Table Register constitutes the baseline state of the facility at the time of the initial study. Post-project states are represented by subsequent editions showing stream movement from higher to lower tiers. Requirements are specified in Section 14.

3.18 MEROS Verified

The independent measurement, monitoring, and verification service that confirms actual emission reductions achieved through implementation of MEROS de-carbonisation opportunities against the predictions of the MEROS Projects MAC curve. A MEROS Verified report constitutes independently verified evidence of emission reduction suitable for use in regulatory compliance submissions, OGMP 2.0 Level 5 reporting, and voluntary carbon market credit generation. Requirements are specified in Section 12.6 and Annex E.

3.19 Marginal Abatement Cost (MAC) curve

A graphical representation of all de-carbonisation opportunities identified in a MEROS study, ordered by cost per tonne of CO_2e avoided (the vertical axis) and showing cumulative abatement potential in tonnes CO_2e per year (the horizontal axis). The width of each bar represents the volume of emission reduction achievable if the opportunity is fully implemented; the height represents the cost per tonne. Opportunities with negative cost (net saving) are displayed below the zero axis. The MAC curve is the primary decision-support tool of the MEROS Projects engagement and is described in Section 12.5.

3.20 Baseline state

The documented condition of a facility's emission and energy profile at a defined reference point in time (T_0), derived from the MEROS workshop output. The baseline state is recorded in the MEROS Register and visualised in the MEROS Periodic Table Register. All subsequent post-project states are measured against the baseline to demonstrate emission reduction. The baseline state for a FEED-stage study is the design-basis profile; for an existing plant study, it is the as-built operational profile supplemented by measurement data where available.

4 Principles of the MEROS Methodology

Sections 4.1 through 4.6 are unchanged from Version 1.0 and are reproduced below. Sections 4.7 and 4.8 are new additions in Version 2.0.

4.1 Design-basis primacy

MEROS is anchored in engineering design data, not operational measurement. The Heat and Mass Balance provides thermodynamically consistent stream parameters for the full facility at design conditions, enabling quantitative priority ranking before any hardware is built or any measurement is taken. This principle distinguishes MEROS from conventional LDAR programmes, which are reactive to emissions already occurring, and from generic emission reviews, which rely on qualitative judgement rather than quantitative stream data.

4.2 Proportionate effort

Not all systems in a facility carry equal emission risk. A MEROS study directs team time and engineering effort towards systems with the highest combined methane and flaring CO_2 priority, as determined by the pre-work tier analysis. Very High priority systems receive full systematic analysis; Low priority systems may be reviewed at a summary level or deferred. This proportionality principle allows a comprehensive plant-wide MEROS study to be conducted in the same elapsed time as a conventional HAZOP of a single process unit.

4.3 Dual-metric assessment

MEROS evaluates emission risk through two independent but complementary metrics. The WMN addresses fugitive methane loss through leakage. The WCN addresses CO_2 consequence from flaring. Neither metric alone is sufficient. The combined tier represents the worst-case of both metrics and drives workshop prioritisation.

4.4 Systematic guideword discipline

Every release point in every MEROS node is assessed against every SCAMPERO guideword. No guideword may be omitted on the grounds that it is unlikely to yield a recommendation. This discipline mirrors the HAZOP principle that every guideword must be applied to every node.

4.5 Multi-discipline ownership

Emission reduction is not a single-discipline problem. A MEROS workshop must include representatives of process engineering, operations, maintenance, instrumentation and control, mechanical, piping, HSE, and project management. The action register produced by a MEROS workshop carries distributed ownership across disciplines, with individual accountability for each action.

4.6 Living document obligation

A MEROS study completed at FEED is not a permanent record of a plant's emission sources; it is the first edition of a living document. As a plant evolves through detailed design, commissioning, operations, modification, and expansion, the MEROS study must evolve with it. The evergreen maintenance obligation defined in Section 11 requires periodic revalidation and Management of Change-triggered updates.

> **NEW IN v2.0:** *Sections 4.7 and 4.8 are new additions in Version 2.0.*

4.7 Baseline documentation primacy

A MEROS study establishes a timestamped, signed, and formally controlled baseline state of the facility's emission profile. This baseline — the T_0 reference — is the foundation against which all subsequent emission reductions are measured, reported, and verified. The baseline state is not an estimate or a model output: it is a documented engineering assessment derived from the facility's design basis, reviewed by a multi-discipline team, and recorded in the MEROS Register. Its integrity is essential to the credibility of all downstream project and verification claims.

The MEROS Periodic Table Register (Section 14) provides the visual representation of the baseline state. It records every stream's tier assignment at T_0 and serves as the primary reference document for the MEROS Projects MAC curve and MEROS Verified pre/post comparison. Once issued, the baseline state may only be revised through the evergreen maintenance process defined in Section 11 or through a formal Management of Change update.

4.8 Evidence chain integrity

The MEROS methodology is designed to produce an unbroken evidence chain from initial source identification through to independently verified emission reduction. Each stage of the chain produces a formally controlled document: the MEROS Register (pre-work and workshop output), the MEROS Projects portfolio (quantification and project programme), and the MEROS Verified report (post-project measurement and verification). No stage may be skipped or substituted without breaking the chain. An evidence chain that satisfies all three stages constitutes the strongest available demonstration of systematic, traceable, and verified emission management — the standard required by OGMP 2.0 Gold Standard, EU Methane Regulation Article 12, and voluntary carbon market protocols.

5 Pre-work: Priority Determination

Sections 5.1 through 5.6 are unchanged from Version 1.0 and govern the pre-work phase: purpose of pre-work, the SBEM hierarchy, WMN calculation, WCN calculation, priority tier assignment, and node definition. These sections are not reproduced in full in this change summary. Refer to Version 1.0 for the complete text of Sections 5.1–5.6.

> **NEW IN v2.0:** *Sections 5.7 and 5.8 are new additions in Version 2.0.*

5.7 WCN driver classification

Following the calculation of WCN Intensity and WCN Rate for each stream (Sections 5.4), the pre-work engineer shall classify each in-scope stream by its primary WCN driver. The driver classification is determined as follows:

- Rate-driven (R): the stream's WCN Rate percentage of peak ($\dot{M}_R\%$) exceeds or equals its WCN Intensity percentage of peak ($\dot{M}_I\%$). The blocked-discharge vapour flow volume is the dominant risk factor. Engineering response: flare gas recovery compressor, ESD valve philosophy review, blowdown sequencing optimisation, cold flare header routing.
- Intensity-driven (I): the stream's WCN Intensity percentage ($\dot{M}_I\%$) exceeds its WCN Rate percentage ($\dot{M}_R\%$). The heavy hydrocarbon composition of the stream is the dominant risk factor. Engineering response: vapour recovery unit, stream rerouting to process feed or fuel gas, combustion efficiency improvement, alternate flare tip specification.

The driver classification shall be recorded in the node definition record alongside the WCN Intensity and WCN Rate tier assignments. The driver is displayed on the MEROS Periodic Table Register as a small badge (R or I) on each stream element. In the MEROS Projects MAC curve, Rate-driven and Intensity-driven opportunities are differentiated by colour to direct the engineering response to the correct project category.

> **NOTE:** *Where WCN Rate % equals WCN Intensity % exactly, the stream shall be classified Rate-driven (R) by convention. This is an infrequent condition arising from coincidental numeric equality in the normalised scores.*

5.8 Combined DEEI score for node sequencing

The combined DEEI score is a single composite priority indicator for each MEROS node, used to determine the sequence in which nodes are reviewed in the MEROS workshop (Section 9.1). The combined score is calculated as:

Combined DEEI score = max(WMN tier rank, WCN combined tier rank)

Where tier rank values are: Very High = 4, High = 3, Medium = 2, Low = 1, Out of Scope = 0. The node with the highest combined DEEI score is reviewed first. Within the same combined DEEI score, the node with the higher individual WMN tier rank is reviewed before nodes with higher WCN tier rank, reflecting the greater regulatory focus on fugitive methane in current frameworks. The leader may vary this sequence where process connectivity or team availability considerations apply.

6–11 Release Taxonomy, Root Causes, Team Composition, Workshop Process, Documentation, Lifecycle

Sections 6 through 11 are unchanged from Version 1.0. They govern the release type taxonomy (Section 6), root cause taxonomy (Section 7), team composition and qualifications (Section 8), workshop process (Section 9), documentation and deliverables (Section 10), and lifecycle and evergreen maintenance (Section 11).

> **NOTE:** *Section 10.5 (MEROS Periodic Table Register as a formal deliverable) and Section 10.6 (MEROS Projects portfolio document requirements) are added in Version 2.0 and are described within Section 14 below for clarity.*

12 Relationship to Other Studies and Regulatory Frameworks

Sections 12.1 through 12.4 are unchanged from Version 1.0. They govern MEROS's relationship to HAZOP (12.1), LDAR programmes (12.2), flaring reduction programmes (12.3), and regulatory alignment (12.4).

> **NEW IN v2.0:** *Sections 12.5 and 12.6 are new additions in Version 2.0.*

12.5 MEROS Projects

MEROS Projects is the structured process by which the de-carbonisation opportunity register produced by the MEROS workshop is translated into a sanctionable project portfolio. It addresses the gap between opportunity identification and capital allocation decision — the point at which most LDAR and emission reduction studies fail to produce lasting change.

12.5.1 CO_2e quantification

Every de-carbonisation opportunity in the MEROS Register shall be quantified in terms of annual CO_2e reduction achievable if the opportunity is fully implemented. Quantification follows the release type of the opportunity:

- Fugitive emissions (FE): component-level emission factors from EPA AP-42 or CCAC OGMP guidance, multiplied by component count from the P&ID, methane fraction, and GWP_{100} for methane. See Annex D for the full methodology.
- Venting (V): volumetric flow rate from HMB × methane content × event frequency × duration × GWP_{100}.
- Flaring (F): WCN Rate metric converted to continuous annual CO_2 tonnes using operating hours, plus methane slip from incomplete combustion (1.5–2% of inlet methane) at GWP.
- Engine and fuel burning (EB/FB): IPCC emission factors for fuel type × throughput, plus methane slip factors by equipment type.

12.5.2 Cost of reduction estimation

Each opportunity is assigned a Class 5 capital cost estimate (accuracy ±50%) using the implementation pathway classification below. The purpose of the estimate is to distinguish the order of magnitude of cost (£10K vs £1M vs £10M), not to produce a definitive procurement cost.

Implementation pathway	Cost range (£)	Examples
Process change / procedure modification	5,000–60,000	Startup/shutdown procedure change, operating set-point modification, maintenance practice revision
Software / control change	10,000–80,000	DCS logic modification, smart controller installation, ESD philosophy change
Hardware change — minor	20,000–400,000	Valve packing replacement programme, dry seal retrofit, pneumatic device replacement, low-emission gasket

		specification
Minor capital project	200,000–3,000,000	Vapour recovery unit, flare gas recovery compressor, instrument air system extension, piping reroute
Major capital project	1,000,000–20,000,000+	Instrument air grassroots system, pipeline infrastructure, full train reconfiguration, compression train replacement

12.5.3 Marginal Abatement Cost curve

The MAC curve is the primary deliverable of MEROS Projects. It presents every de-carbonisation opportunity in a single chart, ordered by MAC (£/tCO_2e avoided per year) on the vertical axis, with cumulative abatement potential (tCO_2e/year) on the horizontal axis. The width of each bar represents the volume of reduction achievable; the height represents the cost per tonne. Opportunities with negative MAC (net saving through reduced fuel, recovered product, or avoided maintenance) are displayed below the zero axis.

The MAC curve shall distinguish Rate-driven and Intensity-driven opportunities by colour, and shall annotate each bar with its implementation pathway category. The curve is the primary document for capital allocation committee presentation, regulator submission, and investor ESG reporting.

12.5.4 Project portfolio document

The MEROS Projects engagement produces a project portfolio document containing: the MAC curve; a project register with scope, cost estimate, implementation schedule, and owner for each opportunity; a programme Gantt chart showing implementation sequence; a cumulative emission reduction profile showing facility methane intensity over time as projects complete; and a capital requirement schedule.

12.5.5 Business case framework

Each de-carbonisation opportunity shall be framed in one or more of the following business case formats, selected according to the operator's regulatory and commercial context:

- Carbon price business case: annual CO_2e reduction × prevailing ETS or internal carbon price = annual financial value. Compare against implementation cost to determine payback period and NPV.
- Regulatory compliance business case: opportunity eliminates a non-compliant emission source, avoiding a regulatory penalty or a compliance risk. Compliance spend does not compete for capital in the same way as discretionary investment.
- Operational value business case: recovered methane routed to fuel gas or sales gas has direct commodity value. At typical European gas prices, 1 tonne of methane recovered per day generates approximately £1.5–2M per year of product value.

The most robust business cases combine all three: regulatory value avoided + product value recovered + carbon credit value generated. The combined NPV at a project-specific discount rate is the primary submission document for capital sanction.

12.6 MEROS Verified

MEROS Verified is the independent measurement, monitoring, and verification (MRV) service that confirms actual emission reductions against the predictions of the MEROS Projects MAC curve. It closes the evidence chain from design-basis identification through to independently verified reduction.

12.6.1 Baseline establishment

The MEROS workshop output — the pre-project de-carbonisation opportunity register and MEROS Periodic Table Register (Section 14) — constitutes the documented baseline. Stream conditions, identified emission sources, estimated volumes, and current detection status from the MEROS Register define the T_0 reference against which post-project performance is measured. The baseline shall be formally signed and document-controlled before any project implementation begins.

12.6.2 Implementation monitoring

During project execution, the MEROS Verified practitioner shall provide periodic inspection reports confirming that hardware changes have been installed as specified, control system changes have been commissioned to the design intent, and procedural changes have been implemented and trained out. Implementation monitoring reports constitute the audit trail that demonstrates the project was delivered as designed — a prerequisite for the post-project measurement phase.

12.6.3 Post-project measurement

Following project completion, actual emission rates shall be measured using methods aligned with OGMP 2.0 Level 5 (source-level direct measurement). Acceptable measurement methods include:

- Portable optical gas imaging (OGI) with quantification — for fugitive emissions from individual components;
- Continuous fixed-point sensors with calibrated volumetric flow integration — for venting and continuous emission sources;
- Aerial or satellite cross-check at facility level — for verification of aggregate emission reduction;
- Process data integration — for streams with direct metering, where meter accuracy and calibration are certified.

Measurements shall be taken under operating conditions representative of the design case and shall cover a minimum of 30 continuous operating days, or three representative operating events for intermittent sources.

12.6.4 Verification report

The MEROS Verified report shall state: the predicted emission reduction from the MEROS Projects MAC curve (tCO_2e/year); the actual measured emission reduction (tCO_2e/year); the verification conclusion (full delivery, partial delivery with explanation, or shortfall with corrective action recommendation); and the MEROS Verifier's signed statement of independent verification. The report shall be prepared by a qualified MEROS Verifier (see Annex E for qualification requirements) who is independent of the project implementation team.

12.6.5 Carbon credit and regulatory use

A MEROS Verified report, backed by the complete evidence chain (MEROS Register baseline, MEROS Projects MAC curve, implementation monitoring records, and post-project measurement data), constitutes a verified emission reduction record suitable for: EU ETS compliance demonstration; OGMP 2.0 Gold Standard Level 5 reporting; voluntary carbon market credit issuance under applicable standards; and regulatory compliance evidence under EU Methane Regulation 2024/1787 Article 12.

13 Limitations and Boundary Conditions

Section 13 is unchanged from Version 1.0. It governs the limitations of WMN and WCN calculations, HMB data quality dependencies, team knowledge constraints, and the exclusion of non-methane greenhouse gases. Refer to Version 1.0 for the complete text.

14 MEROS Periodic Table Register

NEW IN v2.0: *Section 14 is new in Version 2.0.*

14.1 Purpose

The MEROS Periodic Table Register is a standardised visual representation of the MEROS priority register. It presents every stream in a facility as a discrete element in a structured grid, arranged to communicate priority, process grouping, and scope simultaneously — without requiring the reader to interpret a ranked list or data table. The Periodic Table Register is designed to be printed at A1 size and displayed in project offices, control rooms, and engineering team workspaces as a permanent reference for LDAR planning, FEED design decisions, and management communication.

The Periodic Table Register is not a substitute for the MEROS Register — it is a navigational map that makes the register accessible to all disciplines, including those who did not participate in the MEROS workshop. It is the primary communication artefact of the MEROS methodology for non-technical stakeholders.

14.2 Structure

The Periodic Table Register shall be structured as follows:

- Main table: streams are arranged in a grid with four vertical bands (left to right: Very High, High, Medium, Low) and rows corresponding to process sections (SBEM L4 Unit). Within each band/row cell, stream elements are arranged in decreasing order of WMN score (MethaneScan register) or combined WCN score (FlareCO2Scan register).
- OOS island: streams classified as Out of Scope (zero methane for MethaneScan; liquid phase for FlareCO2Scan) are displayed in a separate row or rows below the main table, separated by a visual gap, analogous to the lanthanide and actinide series in the periodic table of elements. The OOS island shall clearly state the reason for exclusion.
- Element encoding: each stream element box shall display the stream number (primary identifier) in a size sufficient for legibility at A1 printing. The element box may additionally display the stream phase (G/L/M), operating pressure, and WCN driver classification (R/I for FlareCO2Scan). No numerical WMN or WCN values shall be shown on the element — these remain in the MEROS Register.
- Tier colour coding: Very High = red; High = amber; Medium = blue; Low = green; OOS = grey (MethaneScan) or blue (FlareCO2Scan liquid OOS).
- Direction indicator: a visual indicator shall show the direction of decreasing methane/CO_2 potential from left (highest) to right (lowest).

14.3 Baseline and post-project states

The initial issue of the Periodic Table Register, produced at the time of the MEROS workshop, constitutes the Baseline State. It shall be labelled "BASELINE — PRE-PROJECT" and shall include the date of issue, the HMB reference, and the MEROS study reference.

As de-carbonisation projects are completed and verified, subsequent editions of the Periodic Table Register shall show stream elements at their new (post-project) tier position. Streams that have moved from a higher to a lower tier shall carry a directional arrow showing their origin tier, providing a visual audit trail of the emission reduction programme's progress. A stream that has been eliminated as an emission source (routed permanently to a closed system, converted from gas-driven to air-driven, or otherwise fully mitigated) shall be moved to the OOS island.

The visual progression of stream elements from the left (high-risk) bands to the right (low-risk) bands, and from the main table to the OOS island, constitutes the primary visual evidence of the decarbonisation programme's effectiveness.

14.4 PFS and UFS cross-reference

The stream numbers displayed in the Periodic Table Register shall correspond directly to the stream numbers used in the facility's Process Flow Scheme (PFS) and Utility Flow Scheme (UFS). Operators shall cross-reference the Periodic Table Register against the PFS/UFS to:

- Mark Very High and High priority piping runs on the PFS in the corresponding tier colour — creating a colour-coded PFS that defines the inspection walk-down route by priority;
- Cross off Out of Scope streams from the LDAR inspection route — formally documenting that those piping runs require no methane inspection, with reference to the MEROS Register as the justification;
- Identify high-priority equipment items (compressors, exchangers, vessels) by locating their inlet and outlet streams in the high-priority bands of the Periodic Table Register.

The PFS marked up using the Periodic Table Register cross-reference constitutes the LDAR Walk-Down Route Document and shall be maintained under formal document control alongside the MEROS Register.

14.5 Document control

The Periodic Table Register shall be maintained under the same document control regime as the MEROS Register. Each edition shall carry a revision number, date of issue, and the name of the responsible MEROS leader. Revisions shall be triggered by the same events that trigger MEROS Register updates: periodic revalidation, Management of Change events, and project close-out (Section 11).

Annex A — Component Combustion Stoichiometry

Annex A is unchanged from Version 1.0. It provides the number of moles of CO_2 produced per mole of each HMB component under complete combustion conditions for use in the WCN Intensity calculation. Refer to Version 1.0 for the complete table.

Annex B — Glossary of Abbreviations

NEW IN v2.0: *The following abbreviations are added in Version 2.0. Refer to Version 1.0 for the complete v1.0 glossary.*

Abbreviation	Expansion	Version
DEEI	Design-Basis Emission and Energy Indicators — the WMN/WCN/WEN family	2.0 NEW
MAC	Marginal Abatement Cost — cost per tonne CO_2e avoided per year	2.0 NEW
MEROS Verified	Independent measurement and verification service for MEROS de-carbonisation projects	2.0 NEW
MRV	Measurement, Reporting, and Verification	2.0 NEW
PT Register	MEROS Periodic Table Register — visual baseline documentation format	2.0 NEW
WEN	Weighted Energy Number — HMB-derived energy recovery potential metric (specified separately)	2.0 NEW
PFS / UFS	Process Flow Scheme / Utility Flow Scheme — plant engineering drawings cross-referenced with PT Register	2.0 NEW

All abbreviations from Version 1.0 (BDV, CCAC, EDV, EPA, FE, FEED, FlareCO2Scan, FGRC, FRP, GHG, GHGRP, HAZID, HAZOP, HMB, HSE, IEC, IEA, L1–L5, LDAR, MEROS, MethaneScan, MoC, OGMP, OGI, OOS, P&ID, PRV/PSV, SBEM, SCAMPERO, VH/H/M/L, VRU, WCN, WMN) are retained and unchanged.

Annex C — MEROS Node Record Template

Annex C is unchanged from Version 1.0. It defines the minimum content of a MEROS node record. Refer to Version 1.0 for the complete template.

Annex D — MEROS Projects Methodology

NEW IN v2.0: *Annex D is new in Version 2.0.*

D.1 CO_2e quantification by release type

The following methodology shall be used to quantify the CO_2e reduction potential of each de-carbonisation opportunity identified in the MEROS Register. Global Warming Potential (GWP) factors shall be taken from the most current IPCC Assessment Report (currently AR6: GWP_{100} for CH_4 = 28.5 over fossil fuel origin).

Release type	Quantification method	Primary data sources
Fugitive emission (FE)	Component count × emission factor (kg/hr/component) × methane fraction × 8,760 hr/yr × GWP_{100}	EPA AP-42 Table 5.2; CCAC OGMP Table 3; P&ID component count
Venting (V)	Event frequency × event duration × volumetric flow rate × methane content × density × GWP_{100}	HMB stream flow rate; operating procedures for frequency/duration
Flaring (F)	Flaring hours/yr × WCN Rate (t CO_2/hr) + methane slip (1.5–2% of CH_4 inlet × GWP_{100})	HMB vapour flow; WCN Rate from pre-work; DCS flaring data for existing plant
Engine burning (EB)	Fuel consumption rate × CH_4 slip factor by engine type × GWP_{100} (slip) + fuel CO_2 from combustion	IPCC 2019 emission factors; equipment datasheets for fuel consumption
Fuel burning (FB)	Fuel consumption rate × CO_2 emission factor by fuel type	IPCC 2019; equipment datasheets

D.2 MAC curve construction

The MAC curve shall be constructed using the following steps:

- Step 1: List all de-carbonisation opportunities from the MEROS Register rated High or Medium Impact.
- Step 2: Assign a CO_2e reduction estimate (Section D.1) and a capital cost estimate (Section 12.5.2) to each opportunity.
- Step 3: Calculate MAC = net annualised cost (£/yr) / CO_2e reduction (tCO_2e/yr). Net annualised cost = capital cost × CRF + annual O&M cost − annual savings (recovered product value + avoided energy cost). Capital Recovery Factor (CRF) = $r(1+r)^n / ((1+r)^n - 1)$ where r = discount rate (typically 8–10%) and n = project life (typically 20 years).
- Step 4: Sort all opportunities by MAC value in ascending order (most negative first).
- Step 5: Plot as a waterfall chart with cumulative tCO_2e/yr on the horizontal axis and MAC (£/tCO_2e) on the vertical axis. Each bar's width = tCO_2e reduction; height = MAC value.

- Step 6: Annotate each bar with stream reference(s), implementation pathway, and driver classification (Rate/Intensity).

D.3 Implementation pathway classification

Each opportunity shall be classified by implementation pathway (see Section 12.5.2). The pathway determines the implementation timeline and cost structure, which in turn determines the programme Gantt chart and capital requirement schedule. Quick wins (process change, minor hardware) shall be sequenced in the first 12 months; anchor projects (minor capital) in months 12–36; infrastructure projects in months 36+.

Annex E — MEROS Verified Framework

NEW IN v2.0: *Annex E is new in Version 2.0.*

E.1 MEROS Verifier qualification requirements

The MEROS Verifier shall hold the following minimum qualifications:

- Chartered or registered Process Engineer with a minimum of ten years of experience in oil and gas process design or operations;
- Completion of the MEROS Leader certification programme (Section 8.1);
- Completion of the MEROS Verifier specialist course (two days, covering MRV methodology, measurement technique selection, uncertainty analysis, and verification report preparation);
- Independence from the project implementation team for the facility under verification — the MEROS Verifier shall not have been involved in the design, procurement, or construction of the projects being verified.

E.2 Verification report minimum content

The MEROS Verified report shall contain as a minimum:

- Facility identification: name, location, operator, HMB reference, MEROS Register reference;
- Baseline reference: T_0 MEROS Register edition, baseline Periodic Table Register edition, baseline emission volume (tCO_2e/yr) by release type;
- Project scope: list of de-carbonisation projects covered by this verification, with MEROS Register opportunity reference for each;
- Predicted reduction: total tCO_2e/yr reduction predicted in MEROS Projects MAC curve for the covered projects;
- Measurement methodology: measurement method used for each project, measurement period, calibration records, and uncertainty estimate;
- Measured reduction: actual tCO_2e/yr reduction measured, broken down by project;
- Verification conclusion: one of (a) Full delivery — measured reduction ≥ 95% of predicted; (b) Partial delivery — measured reduction 70–95% of predicted, with explanation; (c) Shortfall — measured reduction < 70% of predicted, with corrective action recommendation;
- Post-project Periodic Table Register: updated edition showing verified stream tier movements;
- MEROS Verifier signed statement: confirms independence, qualifications, and verification conclusion.

E.3 Uncertainty management

Measurement uncertainty shall be quantified and reported for each measurement method used. The combined uncertainty of the verified reduction shall be stated as a percentage at 95% confidence. Where combined uncertainty exceeds 20%, the verification conclusion shall be downgraded by one category (Full to Partial; Partial to Shortfall). Uncertainty shall be reduced through the use of direct measurement at source level (OGMP 2.0 Level 5) in preference to engineering calculation or activity data-based estimation.

E.4 Frequency and renewal

MEROS Verified reports shall be produced at the following intervals:

- Within 12 months of project mechanical completion, for each project covered by the verification scope;
- Annually thereafter, for facilities subject to mandatory emission reporting under EU Methane Regulation 2024/1787 or equivalent national regulation;
- Every three years for all other verified facilities, or upon significant change to the operating profile.

Acknowledgements

The MEROS methodology was developed through applied research in hydrocarbon processing design and the systematic analysis of methane and flaring CO_2 emission sources across oil and gas facility types. The authors acknowledge the foundational contribution of the HAZOP methodology (IEC 61882) as the structural model from which MEROS's workshop discipline, guideword approach, and action close-out process are derived.

The pre-work tools MethaneScan and FlareCO2Scan are published as open-source software under the MIT licence and are freely available for use by the global engineering community. Their underlying calculation methods — choked-flow orifice equations for methane leak potential and complete combustion stoichiometry for flaring CO_2 intensity — are drawn from established process engineering practice and publicly available regulatory guidance. Both tools have been validated against a real 175-stream LNG plant Heat and Mass Balance (EP BOD Summer case), confirming the methodology produces consistent and physically meaningful priority rankings across a full facility stream population.

The MEROS Periodic Table Register visual format, introduced in Version 2.0, draws structural inspiration from the periodic table of elements as a canonical example of a visual communication system that encodes priority, grouping, and categorical information simultaneously without numerical data. The use of this format for emission priority communication is original to the MEROS methodology.

The authors invite peer review, commentary, and challenge from the academic, standards, and practitioner communities. All feedback received will be considered in the preparation of subsequent revisions.

— End of Document —

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