C A R B O T U R A

ACM Manufacturing Center

Life Cycle Assessment Methodology Framework

ISO 14040/14044-aligned scoping document for facility-level, module-level, and product-level LCA. Defines system boundary, functional units, allocation rules, comparator basis, uncertainty methodology, and EPD pathway for 116 products across 8 refining families.

Document Class: **Room 2 — Technical Portal (NDA Required)**

Version: LCA-001 Rev 1.0 — Design Basis

Standard: ISO 14040:2006 / ISO 14044:2006 / ISO 14044:2006/Amd 1:2017 / ISO 14044:2006/Amd 2:2020

DESIGN-BASIS SCOPING DOCUMENT

This document defines the methodology that will be applied when conducting the ISO 14040/14044 certified LCA in Year 1 of operations. All numerical figures referenced herein are design-basis estimates that will be replaced by measured operational data during the certified LCA. This document is intended for review by the third-party LCA practitioner prior to commissioning.

1. Purpose and Scope

This LCA Methodology Framework defines the approach that will be applied when conducting the Life Cycle Assessment (LCA) of the Carbotura ACM Manufacturing Center and its 116 product outputs. It is a scoping document — it establishes the methodology before operational data is available — so that the certified LCA practitioner, validators, and offtakers can review and agree the approach prior to commissioning.

The framework covers three LCA levels:

- Facility-level LCA — the environmental performance of the ACM Manufacturing Center as a single system, processing manufacturing feedstock into all 116 product outputs and Island Mode electricity
- Module-level LCA — the environmental performance of each of the eight product family process modules (CRB, MTL, GLS, GAS, ARM, MIN, WTR, WTR-FC)
- Product-level LCA — the cradle-to-gate carbon intensity and other impact categories for each individual product

Document ID	LCA-001

Standard	ISO 14040:2006 and ISO 14044:2006 (including Amendments 1:2017 and 2:2020)
Additional guidance	EN 15804:2012+A2:2019 (EPD core rules, construction sector); PCR 20000 (Product Category Rules — pending selection)
LCA type	Attributional LCA (primary); Consequential LCA (supplementary — for avoided methane system expansion)
Scope	Facility, module, and product levels; 116 products across 8 families
Anchor documents	FEP-001 Facility Environmental Profile v1.0; CR-001 Claims Register v1.0; CMD-001 CDR Methodology Document v1.0
Third-party reviewer	TBD — selection pending; shortlist: PRé Sustainability, Sphera, Intertek
Certified LCA target	Year 1 Q3 post-COD (following 12 months of operational data)

2. Goal and Scope Definition

2.1 Goal of the LCA

The primary goal of the Carbotura LCA is to provide quantified, third-party-verified environmental performance data for:

- Product-level carbon intensity (kg CO2e per tonne) for all 116 products — the basis of the "Designed carbon impact" figures on the RevCon portal
- Facility-level net carbon balance — confirming the designed negative carbon outcome including CDR products and avoided methane
- Comparative assertions against reference products (virgin synthetic graphite, primary copper, primary aluminium) — ISO 14044 §4.3.4
- EPD (Environmental Product Declaration) basis for each product family — ISO 14025
- CDR registry credit quantification basis — supporting CMD-001 Puro.earth methodology

The secondary goal is to identify the highest-impact parameters in the facility design for engineering optimisation — particularly energy efficiency in the CRB graphitisation train (the largest single energy consumer) and reagent consumption in the MTL hydrometallurgical modules.

2.2 System Boundaries

Facility-Level System Boundary: Gate-to-Gate + System Expansion

The primary system boundary is gate-to-gate: from manufacturing feedstock intake (the facility gate) to product output (at the facility gate). All internal processes are included. Upstream (feedstock collection, transport) and downstream (product use, end-of-life) are outside the primary boundary but are reported separately as Scope 3.

> System boundary diagram: Manufacturing feedstock intake → [Pregenesis sorting → Recyclotron MCR → Product cascades (CRB/MTL/GLS/GAS/ARM/MIN/WTR/WTR-FC) → Island Mode PEM fuel cell] → All 116 product outputs + internal electricity. The dashed outer boundary for system expansion includes: avoided landfill methane (counterfactual feedstock fate) and displaced primary product production (for comparative assertions).

What is INSIDE the system boundary

- All process modules from feedstock intake to product output
- Internal energy generation (PEM fuel cell — 100% of facility electricity)
- Internal water treatment and WTR-FC water production
- All reagent and chemical inputs to process modules
- Facility infrastructure (amortised over 20-year design life)
- Carbon sequestered in CRB products and MIN-004 PCC (CDR credit)

What is OUTSIDE the primary boundary (Scope 3 — reported separately)

- Manufacturing feedstock collection and transport to facility (Feedstock Hauler fleet)

- Reagent manufacturing (upstream of facility gate)
- Product distribution from facility gate to customer
- Customer use phase and product end-of-life
- Facility construction and decommissioning

System Expansion (ISO 14044 §4.3.4 — supplementary)

A supplementary system expansion analysis is conducted for two purposes:

- Avoided landfill methane: the counterfactual fate of the manufacturing feedstock (sanitary landfill) generates methane (CH_4, GWP-100 = 27.9, IPCC AR6). The avoided methane is a system expansion credit included in the facility-level climate benefit (per FEP-001 Section 6.1) but NOT in product-level carbon intensity figures.
- Displaced primary production: for comparative assertions (Section 6), the LCA assesses the carbon intensity of the primary product that Carbotura output displaces (virgin synthetic graphite, primary copper, etc.). This supports ENV-002 comparative claims per CR-001 Claims Register.

2.3 Functional Units

Three functional units are used at different LCA levels:

LCA Level	Functional Unit	Rationale
Facility-level	1 tonne of manufacturing feedstock processed	Reflects the facility's primary input; enables comparison across facility scales (100/400/1,000/2,000 TPD configurations)
Module-level	1 tonne of primary product output from that module	Enables comparison of module efficiency; relevant for engineering optimisation
Product-level (CRB, MTL, GLS, MIN, ARM)	1 tonne of product delivered at facility gate	Standard product LCA functional unit; enables comparator benchmarking
Product-level (GAS)	1,000 Nm^3 of gas product delivered at facility gate	Standard gas product unit; consistent with industrial gas LCA practice
Product-level (WTR, WTR-FC)	1 m^3 (1,000 kg) of water product delivered at facility gate	Standard water product unit; consistent with ISO 14046 water footprint

2.4 Reference Flows

Reference flows define the quantities of materials and energy required to deliver the functional unit. For the product-level LCA, the reference flow is determined by the yield per tonne of manufacturing feedstock input, as documented in the Mass Balance Framework (LCA-002, pending).

The product yield data (tpd_100, tpd_400, tpd_1000, tpd_2000 fields in the product specs) are design-basis reference flows. The certified LCA will replace these with measured operational reference flows from commissioning data.

3. Allocation Methodology

Allocation is required because the Carbotura facility co-produces 116 products from a single input (manufacturing feedstock). ISO 14044 §4.3.4 provides a hierarchy of allocation approaches. This framework applies the hierarchy as follows:

3.1 ISO 14044 Allocation Hierarchy

Preference	Method	Application in Carbotura LCA
1st (preferred)	System expansion — avoid allocation by expanding the system boundary to include displaced products	Applied for: avoided landfill methane (facility-level); comparative assertions against primary products (product-level ENV-002 claims). Not applied for main product allocation — 116 co-products makes full system expansion computationally impractical.
2nd	Physical allocation — allocate based on underlying physical relationship (mass, energy, volume)	Applied for: main product family allocation. Mass-based allocation is the primary method. Energy-based allocation is calculated as a sensitivity check.
3rd	Economic allocation — allocate based on economic value of co-products	Applied as: secondary sensitivity analysis only. Economic allocation is not the primary method due to price volatility across the 116 products (range: ~$35/t aggregate to ~$1.2M/t Xenon).

3.2 Mass-Based Allocation (Primary)

Each product's allocated share of facility-level impacts is proportional to its mass output as a fraction of total mass output. The allocation factor for product i is:

$$AF_i = mass_i / \Sigma\ mass_{all\_products}$$

Where mass_i is the annual production mass of product i, and Σ mass_all_products is the total annual production mass of all 116 products combined.

Facility-level impacts allocated to product i = Total facility impact × AF_i

Mass-based allocation is appropriate for this facility because the primary input (manufacturing feedstock) is measured in mass, and the primary purpose of the facility is material conversion — not energy production. ISO 14044 §4.3.4 supports mass allocation when a physical causal relationship exists between the input and the outputs, which is the case here.

3.3 Energy-Based Allocation (Sensitivity)

A secondary sensitivity analysis allocates facility impacts based on the energy content (lower heating value, LHV) of each product output. This is particularly relevant for the GAS family products where energy content is the primary use characteristic.

Energy allocation factor for product i: $AF_i(energy) = LHV_i \times mass_i / \Sigma\ (LHV_j \times mass_j)$

The difference between mass-based and energy-based allocation results provides the uncertainty range for the energy-intensive product families (GAS, ARM). For non-energy products (WTR, CRB, MIN), mass allocation is the more defensible approach.

3.4 Handling of Internal Energy (Island Mode)

The PEM fuel cell stack generates 100% of the facility's electricity from manufacturing feedstock-derived hydrogen. This internal energy generation is handled as follows:

- The hydrogen consumed by the PEM stack is an internal material flow — it does not cross the system boundary
- The electricity generated by the PEM stack is allocated across all process modules in proportion to each module's electricity consumption
- The water produced by the PEM stack (WTR-FC products) receives an allocation of the H2 input mass proportional to its share of total PEM output (electricity + water)
- No grid electricity is purchased — Scope 2 = zero by infrastructure specification (no allocation decision required)

> **Internal Energy Handling Note**
>
> The PEM fuel cell simultaneously produces electricity and water. ISO 14044 requires allocation between these two co-products when their impacts cannot be divided by system expansion. The allocation approach: electricity output allocated by energy content (kWh); WTR-FC water output allocated by mass (kg). This is a mass + energy hybrid allocation applied only to the internal PEM sub-system.

4. Impact Categories and LCIA Method

4.1 Selected Impact Categories

The following impact categories are assessed. GWP-100 is the primary category for all product claims. Additional categories are assessed for EPD completeness and module-level engineering optimisation.

Category	Unit	Method	Purpose	Priority
Global Warming Potential (GWP-100)	kg CO_2e	IPCC AR6 characterisation factors (2021)	Primary claim metric — all product carbon intensity figures; CDR credits; comparative assertions	PRIMARY
Biogenic GWP (GWP-bio)	kg CO_2e	IPCC AR6 — reported separately from fossil GWP	Distinguishes biogenic CDR credit from fossil carbon handling; required for Puro.earth registry	PRIMARY
Primary Energy Demand (PED)	MJ	CML 2016 / ecoinvent background	Facility energy efficiency metric; supports the Island Mode autonomous claim	SECONDARY
Water Consumption (WC)	m^3	AWARE characterisation factors	Validates net water producer claim; required for water product EPDs	SECONDARY
Land Use	m^2 annual crop equivalent	ReCiPe 2016	Validates no-land-use claim (urban feedstock); supplementary	SUPPLEMENTARY
Mineral Resource Scarcity	kg Cu-eq	ReCiPe 2016 — surplus ore model	Relevant for MTL critical mineral displacement claims	SUPPLEMENTARY
Particulate Matter Formation	kg PM2.5-eq	ReCiPe 2016	Module-level air quality metric; Pregenesis train primary source	SUPPLEMENTARY
Acidification (terrestrial)	mol H^+ eq	ReCiPe 2016	Module-level metric; Scope 3 transport primarily	SUPPLEMENTARY

4.2 LCIA Characterisation Method

Primary method: ReCiPe 2016 Midpoint (H) for all categories except GWP

GWP characterisation: IPCC Sixth Assessment Report (AR6, 2021) — GWP-100 values. Key values: CO_2 = 1.0; CH_4 (fossil) = 29.8; CH_4 (biogenic) = 27.9; N_2O = 273

Background database: ecoinvent 3.10 (or latest available at time of certified LCA) for upstream reagent and infrastructure inventory

Foreground inventory: Carbotura facility operational data (commissioning measurements; see Section 7 data quality requirements)

The choice of IPCC AR6 vs. AR5 GWP values affects the methane GWP: AR5 = 28–34, AR6 = 27.9–29.8 (fossil/biogenic). This framework uses AR6 values throughout. If a specific registry or buyer requires AR5 values, a sensitivity run will be provided.

4.3 Carbon Accounting Conventions

Three distinct carbon pools are tracked separately throughout the LCA:

Carbon Pool	Definition	LCA Treatment	Registry Treatment
Biogenic carbon	Carbon from recently living organisms (paper, food, biomass, natural textiles). Fixed from atmospheric CO2 within <100 years.	Biogenic CO2 = 0 at point of intake (IPCC 2006 convention). Sequestration in durable products = negative biogenic GWP credit.	CDR-eligible under Puro.earth MC2.1. Quantified separately for registry credit. (CMD-001)
Fossil carbon	Carbon from petroleum-derived materials (plastics, synthetic rubber, synthetic textiles). From geological deposits.	Fossil CO2 from combustion = positive GWP. Sequestration in products = avoided fossil emission (positive credit, not CDR).	Not CDR. Reported as avoided fossil emission in GHG inventory. Separate credit category.
Inorganic carbon	Carbon in mineral carbonates (concrete, limestone, ceramics). Geological origin.	Treated as neutral unless actively mineralised (MIN-004). CO2 from carbonate decomposition = positive GWP.	Not CDR. Treated as Scope 1 emission if released.

5. Uncertainty and Sensitivity Analysis

5.1 Key Uncertainty Sources

The design-basis carbon intensity figures carry uncertainty from five primary sources. The certified LCA will reduce all five through operational measurement:

Uncertainty Source	Design-Basis Range	Dominant Products Affected	Reduction Method
Feedstock biogenic carbon fraction	35–55% (±20% relative)	All CRB and MIN-004 products	ASTM D6866 radiocarbon testing — quarterly; reduces to ±5% relative
Facility Scope 1 emissions allocation	±20% relative	All products (allocated share)	CEMS point-source measurement at commissioning; reduces to ±5%
CRB graphitisation energy per tonne	±15% relative	CRB-008 through CRB-018 (graphitic tier)	Smart meter per graphitisation module at commissioning; reduces to ±3%
MTL reagent consumption per tonne	±25% relative	MTL battery metals (RC3-RC5)	Material balance at each hydromet module; reduces to ±8%
Background ecoinvent data quality	±10% relative (published)	All products (upstream inputs)	Cannot be reduced; stated as epistemic uncertainty in certified LCA

5.2 Sensitivity Analysis Plan

The following sensitivity analyses will be conducted in the certified LCA to bound the uncertainty in key claims:

- Biogenic fraction sensitivity: ±10% around measured value — effect on CRB carbon intensity and CDR credit
- Allocation method sensitivity: mass vs. energy allocation — effect on GAS and ARM family carbon intensities
- Background data sensitivity: ecoinvent 3.10 vs. ecoinvent 3.8 — effect on upstream reagent impacts
- IPCC GWP vintage sensitivity: AR6 vs. AR5 — effect on methane-containing processes
- Scope 1 boundary sensitivity: with and without avoided landfill methane system expansion — effect on facility-level GWP

5.3 How Design-Basis Ranges Were Derived

The ranges in the current "Designed carbon impact" figures (e.g. −3,200 to −4,800 kg CO2e/t for CRB-008) are derived from a Monte Carlo-style propagation of the five uncertainty sources above:

- Lower bound: conservative biogenic fraction (35%), higher Scope 1 allocation, lower graphitisation efficiency

- Upper bound: higher biogenic fraction (55%), lower Scope 1 allocation, higher graphitisation efficiency

The design-basis ranges are intentionally wide to bracket the likely certified result. When the certified LCA narrows these to measured values, the resulting figures will fall within the published ranges on the portal — maintaining the "designed to achieve" claim integrity.

6. Comparator Basis for Comparative Assertions

Three comparative assertions appear in the RevCon product catalog (CR-001 ENV-002). ISO 14044 §4.3.4 requires that comparative assertions use equivalent functional units, system boundaries, and LCA methodology. This section defines the reference LCA basis for each comparator.

6.1 Comparator 1 — Virgin Synthetic Graphite (Coal-Tar Pitch Route)

> **Claim (CRB-008, CRB-018)**
> "Designed to achieve ~99% lower lifecycle carbon intensity vs. virgin synthetic graphite (coal-tar pitch route)"

Functional unit match: 1 tonne of synthetic graphite, equivalent purity and carbon content

Reference LCA sources: Majeau-Bettez et al. (2011) J. Industrial Ecology 15(4):640–654 — synthetic graphite from coal-tar pitch; Dunn et al. (2015) ANL/ESD-14/10 — battery materials LCA; Peters et al. (2017) J. Cleaner Production 162:1</s>–15; Liang et al. (2017) Green Chem. 19:4426–4437

Reference carbon intensity range: 12,000–18,000 kg CO2e per tonne of synthetic graphite (coal-tar pitch route, cradle-to-gate). This range is from the published literature above; the midpoint ~15,000 kg CO2e/t is used for the "~99% lower" comparative claim.

Carbotura design-basis intensity (CRB-008): −3,200 to −4,800 kg CO2e/t (negative — CDR)

Comparative basis: (15,000 − (−4,000)) / 15,000 = 127% improvement — claimed conservatively as "~99% lower" referring to the positive primary production figure alone

Certified LCA requirement: Third-party LCA practitioner to confirm reference LCA selection and recalculate at certified Carbotura intensity; required before comparative assertion moves to certified status

6.2 Comparator 2 — Primary Copper Smelting

> **Claim (MTL-004)**
> "Designed to achieve ~65% lower lifecycle carbon intensity vs. primary copper smelting"

Functional unit match: 1 tonne of copper metal, equivalent purity (≥98% Cu)

Reference LCA sources: ICSG Life Cycle Assessment of Copper Products (2012) — international copper industry LCA; Ecoinvent 3.10 "copper, cathode {GLO}| market" dataset; Northey et al. (2013) Resources, Conservation and Recycling 74:53–67

Reference carbon intensity range: 3,200–4,800 kg CO2e per tonne of primary copper (cradle-to-gate, average global ore grade ~0.7%). Higher end reflects low-grade ores (~0.3%); lower end reflects high-grade operations.

Carbotura design-basis intensity (MTL-004): Not a CDR product. Scope 1 allocated intensity: ~500–1,200 kg CO2e/t (secondary metal recovery — lower than primary due to no mining/beneficiation)

Comparative basis: (3,200 − 1,200) / 3,200 = 62.5%; rounded to "~65%" using midpoint estimates. Conservative — actual improvement likely higher.

Certified LCA requirement: Ecoinvent background dataset for primary copper must be version-matched to Carbotura foreground LCA; sensitivity to ore grade assumption required

6.3 Comparator 3 — Primary Aluminium Smelting

> **Claim (MTL-003)**
> "~95% lower energy intensity vs. primary aluminium smelting from bauxite"

Functional unit match: 1 tonne of aluminium metal, wrought/cast alloy grade

Reference LCA sources: International Aluminium Institute (IAI) Global Life Cycle Inventory Data for Aluminium Production 2021; Ecoinvent 3.10 "aluminium, primary, ingot {GLO}| market"; Paraskevas et al. (2015) J. Cleaner Production 105:314–327

Reference energy intensity: ~170–200 GJ per tonne of primary aluminium (cradle-to-gate; electrolysis dominates at ~15 kWh/kg Al = 54 GJ/t, plus mining/refining ~5 GJ/t and smelter thermal ~15 GJ/t). Published range reflects grid carbon intensity variation.

Reference carbon intensity: 8,000–16,000 kg CO2e/t primary aluminium (cradle-to-gate; heavily dependent on electricity grid carbon intensity of smelter location)

Carbotura design-basis (MTL-003): Secondary aluminium: ~5% of primary energy requirement; ~400–800 kg CO2e/t (design-basis, Island Mode zero-carbon electricity)

Note on claim framing: The "~95% energy reduction" claim is the correct framing — it refers to specific energy consumption (GJ/t), not GHG intensity. GHG reduction varies more because it depends on the comparator grid carbon intensity. Energy reduction is more defensible as a physics-based statement.

Certified LCA requirement: Clarify whether claim is energy intensity or GHG intensity; energy intensity claim is more defensible and should be primary; GHG intensity secondary

7. Data Quality Requirements

7.1 Foreground Data (Carbotura Facility)

The following data quality requirements apply to the Carbotura facility operational data used in the certified LCA:

Data Category	Quality Requirement	Collection Method	Minimum Period
Manufacturing feedstock mass input	Calibrated belt scale, ±0.5% accuracy	Continuous; daily totals logged to facility data system	12 months operational
Product mass outputs (all 116)	Calibrated mass balance per module output, ±1% accuracy	Per production batch; daily totals	12 months
Electricity consumption per module	Smart meter per process module, ±0.5% accuracy	15-minute interval logging	12 months
PEM H2 consumption and water output	Calibrated flow meter + mass balance, ±1%	Continuous	12 months
Scope 1 emissions per point source	CEMS at Pregenesis train exhaust; ±5% accuracy	Continuous; quarterly verification by accredited lab	12 months
Reagent consumption (MTL, GLS, MIN modules)	Mass balance per module per batch	Per batch; monthly totals	12 months
Water consumption / discharge	Calibrated flow meters on all water lines	Continuous; monthly totals	12 months
Feedstock biogenic carbon fraction	ASTM D6866 radiocarbon analysis (accredited laboratory)	Quarterly composite sample	4 quarters minimum

7.2 Background Data (ecoinvent / Published Sources)

Database: ecoinvent 3.10 (or most recent version at time of certified LCA)

Geography: US-specific datasets preferred; global averages where US-specific not available; documented in data quality log

Technology: Average technology datasets (not best-case or worst-case)

Temporal: Datasets from 2020 or later preferred; datasets older than 2010 require justification

Data quality score: Weidema data quality assessment (pedigree matrix) for all significant background flows

7.3 Cut-off Rules

Process inputs and outputs with a contribution of less than 1% to the total GWP impact (and less than 5% cumulatively) may be excluded from the inventory without justification. All excluded flows must be listed. The following flows are expected to be below cut-off for the Carbotura system:

- Lubricants and maintenance chemicals (<0.1% of total mass input)
- Office and administrative infrastructure (<0.5% of facility embodied carbon)

- Personnel transport (excluded per ISO 14044 §4.2.3.3)

8. EPD Pathway

8.1 EPD Structure

An Environmental Product Declaration (EPD) will be produced for each product family, following ISO 14025 and EN 15804:2012+A2:2019. Eight EPDs are planned — one per product family (CRB, MTL, GLS, GAS, ARM, MIN, WTR, WTR-FC). Individual product EPDs will reference the family EPD and include the product-specific allocation results.

EPD Reference	Product Family	Declared Unit	Target PCR	EPD Programme Operator
EPD-CRB-001	Carbon Refining (CRB)	1 tonne of carbon product	EN 15804 / ISO 21930 (construction products — for graphite used in buildings)	IBU (Institut Bauen und Umwelt) or equivalent
EPD-MTL-001	Metals Recovery (MTL)	1 tonne of metal product	EN 15804 / product-specific PCR	IBU or EPD International
EPD-GLS-001	Glass Refining (GLS)	1 tonne of glass product	EN 15804 (construction product glass)	IBU
EPD-GAS-001	Gas Upgrade (GAS)	1,000 Nm³ of gas product	Product-specific PCR for industrial gases	EPD International
EPD-ARM-001	Aromatics (ARM)	1 tonne of aromatic chemical	BASF / PlasticsEurope PCR for chemical products	EPD International
EPD-MIN-001	Minerals (MIN)	1 tonne of mineral product	EN 15804 for construction minerals	IBU
EPD-WTR-001	Water (WTR + WTR-FC)	1 m³ of water product	ISO 14046 water footprint + EPD	EPD International

8.2 EPD Timeline

- Q3 Year 1: Certified LCA complete — provides the verified inventory data for all EPDs
- Q4 Year 1: EPD technical reports prepared — one per family
- Q1 Year 2: EPD programme operator review and publication
- Year 2 onwards: EPDs publicly available at revcon.carbotura.com/engineering/epds/ (Access-gated until public listing confirmed)

9. Certified LCA Execution Plan

9.1 Phases

Phase	Activities	Timeline	Deliverable
0 — Scoping	This document. Third-party LCA practitioner review and approval of methodology.	Pre-commissioning	Approved LCA Methodology Framework (this document, Rev 2.0 post-review)
1 — Data Collection	Facility operational data collection per Section 7 requirements. ASTM D6866 feedstock biogenic fraction testing (4 quarterly samples).	Months 1–12 post-COD	Validated operational inventory dataset
2 — Inventory Analysis	Foreground + background inventory compilation. Mass and energy balance verification against operational data. Allocation calculations.	Month 13	Life Cycle Inventory (LCI) report
3 — Impact Assessment	LCIA calculations for all 8 impact categories. Sensitivity analyses per Section 5.2. Uncertainty propagation.	Month 14	Life Cycle Impact Assessment (LCIA) report
4 — Interpretation + Review	ISO 14044-compliant interpretation. Critical review by independent third party (ISO 14044 §6 — required for comparative assertions). Reconciliation with design-basis figures.	Month 15	Certified LCA report + critical review statement
5 — EPD Publication	EPD technical reports per family. Programme operator review. Public EPD listing.	Months 16–18	EPDs published (one per family)

9.2 Critical Review Requirement

ISO 14044 §6 requires an independent critical review when the LCA will be used for comparative assertions that will be disclosed to the public. The ENV-002 comparative claims (graphite vs. primary synthetic graphite; copper vs. primary copper) constitute such assertions. Therefore a critical review by an independent panel (minimum one LCA expert not associated with Carbotura) is mandatory before the certified comparative claims are published on the portal.

Critical reviewer requirements: ISO 14040/14044 competent; independent of Carbotura and the LCA practitioner; preferably with published work in carbon materials or metals LCA

Critical review scope: Full LCA including comparative assertions; CDR credit quantification; system expansion methodology for avoided methane

10. Document Control

Document ID	LCA-001
Title	LCA Methodology Framework v1.0 — ACM Manufacturing Center
Version	Rev 1.0 — Design Basis (Pre-Commissioning Scoping Document)
Classification	Room 2 — Technical Portal — NDA Required
Standard	ISO 14040:2006; ISO 14044:2006 + Amd 1:2017 + Amd 2:2020; EN 15804:2012+A2:2019
Claims supported	ENV-001 (designed carbon impact figures); ENV-002 (comparative carbon claims) — per CR-001 Claims Register
Related documents	FEP-001 v1.0; CR-001 v1.0; CMD-001 v1.0; LCA-002 Mass Balance Framework (pending)
Next revision	Rev 2.0 following third-party LCA practitioner review and approval; Rev 3.0 = certified LCA Year 1 Q3