C A R B O T U R A

ACM Manufacturing Center

Mass Balance Framework

Engineering input/output tables for all 8 product family process modules. Design-basis mass and energy flows with derivation methodology and verification requirements. Supporting document for FAC-004 (zero waste claim) and ENV-001 (product carbon intensity figures).

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

Document ID: LCA-002 Rev 1.0 — Design Basis

Supports: FAC-004 (Zero Solid Waste) | ENV-001 (Product Carbon Intensity) | LCA-001 (LCA Methodology Framework)

DESIGN-BASIS DOCUMENT

All flows in this document are design-stage estimates derived from engineering stoichiometry, thermodynamic modelling, and analogy with published literature for equivalent process types. They are subject to verification during facility commissioning. No figures constitute certified mass balance results. The verification requirements in Section 3 define what measurement is needed to move each figure to confirmed status.

1. Purpose and Three-Stream Architecture

This document defines the design-basis material inputs and outputs for the Carbotura ACM Manufacturing Center and each of its eight product family process modules. It is the engineering backbone that supports:

- FAC-004 (CR-001 Claims Register) — the zero solid waste claim: every tonne of manufacturing feedstock exits as product
- ENV-001 — the product-level carbon intensity figures in the RevCon catalog (the allocation factors derive from these mass flows)
- LCA-001 (LCA Methodology Framework) — the reference flows for the ISO 14044 certified LCA

1.1 The Three Input Streams

The Carbotura ACM Manufacturing Center has three distinct input streams. All three contribute to product outputs. The mass balance must account for all three to close correctly:

Input Stream	Source	Design-Basis @100	Primary Products

		TPD	
Manufacturing feedstock	Urban commercial and manufacturing materials collected by Feedstock Haulers	100 t/day (the facility capacity unit)	CRB, MTL, GLS, ARM, MIN families; H2 to PEM fuel cell
Atmospheric air (ASU)	Ambient air separated by the cryogenic Air Separation Unit	~30–40 t/day N2+O2+Ar separated	GAS-004 N2, GAS-005 O2, GAS-008 Ar, noble gases (Ne, Xe, Kr)
Process water inputs	Municipal water supply and internal recirculation	~20–30 t/day net consumption	WTR cascade products; reagent water for MTL hydrometallurgy

Mass Balance Closure Note

Total product output mass (279.6 t/day at 100 TPD) exceeds manufacturing feedstock input (100 t/day) because GAS and WTR-FC family products incorporate mass from atmospheric air and PEM water-of-combustion respectively. The feedstock closure rate (CRB+MTL+GLS+ARM+MIN outputs / feedstock input) is ~114%, reflecting the addition of reagent water and oxygen in the downstream processing of feedstock-derived streams. Section 2 documents each family's input sources and closure methodology.

1.2 Facility-Level Summary (@100 TPD Input)

Product Family	Products	Output @100 TPD	Output @400 TPD	Primary Input Source	Closure Basis
CRB	21	51.3 t/d	205 t/d	Manufacturing feedstock organic fraction	Stoichiometric carbon yield from MCR + graphitisation energy balance
MTL	37	13.7 t/d	54.8 t/d	Manufacturing feedstock metallic fraction	Metal content × separation efficiency per ISRI composition data
GLS	12	11.4 t/d	45.8 t/d	Manufacturing feedstock glass fraction	Glass composition × optical sort efficiency; foam glass adds foaming agent mass
GAS	14	71.9 t/d	287 t/d	MCR syngas (feedstock) + ASU (atmosphere)	Syngas composition balance + ASU separation efficiency (Linde/Air Products reference)
ARM	13	20.0 t/d	79.8 t/d	Manufacturing feedstock aromatic condensate	MCR liquid condensate yield × BTX/PAH split by GC analysis model
MIN	6	17.4 t/d	69.4 t/d	Manufacturing feedstock inorganic fraction + CO2 (for MIN-004)	Mineral content × classification efficiency; MIN-004 adds Ca(OH)2 + CO2 mass
WTR	10	60.0 t/d	240 t/d	Process water (feedstock moisture + makeup)	Water balance: feedstock moisture + reagent water + makeup - evaporation - NPDES

WTR-FC	3	34.0 t/d	136 t/d	PEM fuel cell exhaust (H2 + O2 → H2O)	Stoichiometric: 1 kg H2 + 8 kg O2 → 9 kg H2O; H2 throughput × 9
TOTAL	116	279.6 t/d	1,118 t/d	Feedstock + atmosphere + process water	See individual family closures above

2. Family-Level Mass Balance Tables

2.1 CRB — Carbon Refining Cascade

The CRB family converts the organic carbon fraction of the manufacturing feedstock into stable solid carbon products via the Recyclotron MCR and Regenesis/Regenesis MAX process trains. The CRB mass balance is the most significant for the CDR claims — every tonne of CRB output represents feedstock-derived carbon permanently sequestered.

Parameter	@100 TPD	@400 TPD	Derivation
Manufacturing feedstock input (organic fraction)	35–42 t/day C	140–168 t/day C	Feedstock composition: 35–42% carbon by mass (literature: EPA WARM model, Tchobanoglous et al.)
H2 directed to PEM fuel cell (internal)	~2–4 t/day H2	~8–16 t/day H2	MCR syngas H2 yield: ~20–35% of syngas by volume; PEM consumes 100% of H2
CO2 captured → GAS-003 (saleable)	~15 t/day CO2	~60 t/day CO2	MCR CO2 yield from organic carbon: ~35–45% of carbon exits as CO2 in syngas
ARM aromatics condensate (liquid phase)	~19.95 t/day	~79.8 t/day	MCR liquid condensate: ~10–15% of organic input; see ARM family balance
CRB solid carbon products (total)	51.3 t/day	205 t/day	Carbon yield to solid phase: ~30–45% of organic fraction by mass; balance to gas/liquid phases
Process losses (designed)	<2 t/day	<8 t/day	Fugitive carbon losses: <2% of carbon input by design (enclosed process)

CRB product output by RC level:

ID	RC	Product	100 TPD	400 TPD	1,000 TPD	2,000 TPD
CRB-001	RC1	Raw Carbon Char	15.0 t/d	60.0 t/d	150 t/d	300 t/d
CRB-002	RC2	Carbon Black	6.25 t/d	25.0 t/d	62.5 t/d	125 t/d
CRB-003	RC2	Activated Carbon	5.00 t/d	20.0 t/d	50.0 t/d	100 t/d
CRB-004	RC2	Biochar	2.50 t/d	10.0 t/d	25.0 t/d	50.0 t/d
CRB-005	RC2	Standard Graphite	1.80 t/d	7.20 t/d	18.0 t/d	36.0 t/d
CRB-	R	Conductive Carbon	3.75 t/d	15.0 t/d	37.5 t/d	75.0 t/d

006	C 3					
CRB-007	R C 3	High-Grade Carbon Black	3.75 t/d	15.0 t/d	37.5 t/d	75.0 t/d
CRB-008	R C 3	High-Purity Graphite	3.05 t/d	12.2 t/d	30.5 t/d	61.0 t/d
CRB-019	R C 3	Hard Carbon (Na-ion)	1.50 t/d	6.00 t/d	15.0 t/d	30.0 t/d
CRB-009	R C 4	Carbon Fiber Precursor	2.50 t/d	10.0 t/d	25.0 t/d	50.0 t/d
CRB-010	R C 4	Graphene Oxide	0.500 t/d	2.00 t/d	5.00 t/d	10.0 t/d
CRB-011	R C 4	Multi-Walled CNTs	0.300 t/d	1.20 t/d	3.00 t/d	6.00 t/d
CRB-012	R C 4	Synthetic Graphite	2.05 t/d	8.20 t/d	20.5 t/d	41.0 t/d
CRB-018	R C 4	Spheroidized Graphite	1.50 t/d	6.00 t/d	15.0 t/d	30.0 t/d
CRB-020	R C 4	Nanoporous Activated Carbon	1.00 t/d	4.00 t/d	10.0 t/d	20.0 t/d
CRB-021	R C 4	Mesoporous Templated Carbon	0.800 t/d	3.20 t/d	8.00 t/d	16.0 t/d
CRB-013	R C 5	Reduced Graphene Oxide	0.050 t/d	0.200 t/d	0.500 t/d	1.00 t/d
CRB-014	R C 5	Multi-Layer Graphene	0.0050 t/d	0.020 t/d	0.050 t/d	0.100 t/d
CRB-015	R C 5	Single-Layer Graphene	0.0010 t/d	0.0040 t/d	0.010 t/d	0.020 t/d
CRB-016	R C 5	Single-Walled CNTs	0.0020 t/d	0.0080 t/d	0.020 t/d	0.040 t/d
CRB-017	R C 5	Fullerenes (C60/C70)	5.0e-4 t/d	0.0020 t/d	0.0050 t/d	0.010 t/d
TOTAL		21 products	51.3 t/d	205 t/d	513 t/d	1,026 t/d

CRB-020 Nanoporous Activated Carbon does not yet have a designed carbon impact figure — pending process module specification. All other CRB products have carbon impact ranges in the RevCon catalog.

2.2 MTL — Metals Recovery

The MTL family recovers metallic fractions from the manufacturing feedstock via the APS Product Recovery System (ferrous and non-ferrous sorting) and the RC2–RC5 hydrometallurgical and physical separation modules. Metal yields are based on published manufacturing feedstock composition data and equipment separation efficiency specifications.

Parameter	@100 TPD	@400 TPD	Derivation Basis
Manufacturing feedstock metal content	~8–14 t/day total metals	~32–56 t/day	Literature: EPA WARM model; ISRI feedstock composition studies; range reflects feedstock variability
Ferrous metals (APS magnetic separation)	~6.6 t/day (MTL-001)	~26.4 t/day	Ferrous content: ~6–8% of feedstock by mass; APS recovery efficiency: ~92%
Non-ferrous metals (APS eddy current + sort)	~3.4 t/day (MTL-002)	~13.6 t/day	Non-ferrous: ~3–5% of feedstock; APS recovery efficiency: ~85–90%
Battery metals (Black Mass — MTL-045)	~0.5 t/day	~2 t/day	Li-ion battery fraction: ~0.5–1% of feedstock; growing as EV fleet ages
Precious/PGM metals (MTL-012/014/015)	g–kg/day range	See product specs	Electronics density in feedstock × PGM content per WEEE composition data
Total MTL output (all products)	13.7 t/day	54.8 t/day	Sum of all MTL product yield figures; includes trace-volume products

MTL product output by RC level (top 20 by mass; full 37-product list in product specs):

ID	RC	Product	100 TPD	400 TPD	1,000 TPD	2,000 TPD
MTL-001	RC1	Iron / Steel	6.60 t/d	26.4 t/d	66.0 t/d	132 t/d
MTL-002	RC1	Mixed Non-Ferrous	3.40 t/d	13.6 t/d	34.0 t/d	68.0 t/d
MTL-003	RC2	Aluminum	0.750 t/d	3.00 t/d	7.50 t/d	15.0 t/d
MTL-004	RC2	Copper	0.500 t/d	2.00 t/d	5.00 t/d	10.0 t/d
MTL-045	RC2	Black Mass Concentrate	0.500 t/d	2.00 t/d	5.00 t/d	10.0 t/d
MTL-010	RC3	Chromium	0.500 t/d	2.00 t/d	5.00 t/d	10.0 t/d
MTL-050	RC3	Iron Oxide Pigments	0.500 t/d	2.00 t/d	5.00 t/d	10.0 t/d

MTL-005	RC2	Zinc	0.250 t/d	1.00 t/d	2.50 t/d	5.00 t/d
MTL-006	RC2	Lead	0.125 t/d	0.500 t/d	1.25 t/d	2.50 t/d
MTL-007	RC2	Nickel	0.125 t/d	0.500 t/d	1.25 t/d	2.50 t/d
MTL-008	RC2	Tin	0.125 t/d	0.500 t/d	1.25 t/d	2.50 t/d
MTL-009	RC2	Manganese	0.125 t/d	0.500 t/d	1.25 t/d	2.50 t/d
MTL-051	RC4	Lead, Battery-Grade	0.075 t/d	0.300 t/d	0.750 t/d	1.50 t/d
MTL-033	RC3	Cobalt	0.050 t/d	0.200 t/d	0.500 t/d	1.00 t/d
MTL-044	RC4	Lithium Carbonate	0.025 t/d	0.100 t/d	0.250 t/d	0.500 t/d
MTL-046	RC4	Cobalt Sulfate	0.025 t/d	0.100 t/d	0.250 t/d	0.500 t/d
MTL-048	RC4	Lithium Hydroxide	0.015 t/d	0.060 t/d	0.150 t/d	0.300 t/d
MTL-047	RC4	Nickel Sulfate	0.015 t/d	0.060 t/d	0.150 t/d	0.300 t/d
MTL-029	RC4	Cadmium	0.0010 t/d	0.0040 t/d	0.010 t/d	0.020 t/d
MTL-032	RC4	Boron	0.0010 t/d	0.0040 t/d	0.010 t/d	0.020 t/d

2.3 GLS — Glass Refining Cascade

The GLS family recovers glass fractions from the manufacturing feedstock via optical sorting, crushing, milling, and thermal processing. Foam glass (GLS-007, GLS-012) adds a small amount of CRB-002 carbon black as a foaming agent — an internal circular use of a CRB product.

Parameter	@100 TPD	@400 TPD	Derivation
Manufacturing feedstock glass content	~8–12 t/day	~32–48 t/day	Literature: ~8–12% glass in mixed manufacturing feedstock (EPA WARM; Tchobanoglous)
Mixed cullet (GLS-001, after metal removal)	~3.0 t/day	~12 t/day	Glass recovery efficiency: ~85% of glass content; balance = glass fines/contamination
Glass powder (GLS-002, from cullet milling)	~2.0 t/day	~8 t/day	Milling yield: ~65% of GLS-001 converted to GLS-002; balance = course reject to GLS-001
Foam glass (GLS-007 + GLS-012)	~0.8 t/day	~3.2 t/day	GLS-002 + CRB-002 carbon black (~1–2%) → foamed; density reduction factor ~8x; mass ~conserved
Total GLS output	11.4 t/day	45.8 t/day	Sum of all GLS products; Note: cascade products overlap — GLS-003 from GLS-001, etc.

GLS product output:

ID	RC	Product	100 TPD	400 TPD	1,000 TPD	2,000 TPD
GLS-001	RC1	Mixed Glass Cullet	3.00 t/d	12.0 t/d	30.0 t/d	60.0 t/d
GLS-002	RC1	Glass Powder	2.00 t/d	8.00 t/d	20.0 t/d	40.0 t/d
GLS-003	RC2	Color-Sorted Cullet	1.50 t/d	6.00 t/d	15.0 t/d	30.0 t/d
GLS-004	RC2	Glass Aggregate	1.50 t/d	6.00 t/d	15.0 t/d	30.0 t/d
GLS-005	RC3	Recycled Container Glass	1.00 t/d	4.00 t/d	10.0 t/d	20.0 t/d
GLS-006	RC3	Glass Beads	0.750 t/d	3.00 t/d	7.50 t/d	15.0 t/d
GLS-007	RC3	Foam Glass	0.600 t/d	2.40 t/d	6.00 t/d	12.0 t/d
GLS-012	RC	Foam Glass Cellular Block	0.200 t/d	0.800 t/d	2.00 t/d	4.00 t/d

	3					
GLS-008	RC4	High-Quality Cullet	0.400 t/d	1.60 t/d	4.00 t/d	8.00 t/d
GLS-009	RC4	Specialty Glass Powder	0.300 t/d	1.20 t/d	3.00 t/d	6.00 t/d
GLS-011	RC4	Photocatalytic Silica-TiO_2	0.100 t/d	0.400 t/d	1.00 t/d	2.00 t/d
GLS-010	RC5	Ultra-Pure Silica	0.100 t/d	0.400 t/d	1.00 t/d	2.00 t/d
TOTAL		12 products	11.4 t/d	45.8 t/d	115 t/d	229 t/d

The GLS cascade is a hierarchy — higher-RC products are produced from lower-RC intermediate streams. The output table shows the final saleable product at each node, not the total throughput at each process step.

2.4 GAS — Gas Upgrade Cascade

The GAS family has two distinct input streams: (1) the MCR syngas from manufacturing feedstock, which provides CO2, CO, and the noble gas traces; and (2) the Air Separation Unit (ASU), which inputs atmospheric air and separates it into N2, O2, Ar, and noble gases. The H2 in the MCR syngas is internal-only — directed to the PEM fuel cell and never sold.

Parameter	@100 TPD	@400 TPD	Derivation
MCR syngas output (feedstock-derived)	~25–35 t/day	~100–140 t/day	MCR carbon-to-gas conversion: ~25–35% of feedstock organic fraction exits as syngas (H2+CO+CO2+CH4+light HCs)
H2 to PEM (internal — never sold)	~2–4 t/day H2	~8–16 t/day H2	H2 yield from syngas PSA: ~25–45% of syngas volume is H2; all consumed by PEM stack
GAS-003 CO2 (captured, sold)	~15 t/day	~60 t/day	CO2 from syngas + WGS reactor: ~10–25% of syngas by volume; captured by condensation + PSA
GAS-016 CO (pure CO, sold)	~0.5 t/day	~2 t/day	CO from syngas PSA: ~15–30% of syngas by volume; ~2% retained as pure CO product
ASU atmospheric air input	~30–40 t/day air	~120–160 t/day	ASU air throughput per N2+O2+Ar output requirements; ~78% N2, 21% O2, 0.93% Ar by volume
GAS-004/005 N2+O2 output (ASU)	~12.5 t/day each	~50 t/day each	ASU separation: N2 and O2 each ~6.25 t/day net saleable at 100 TPD facility; balance used internally
Noble gases (Ne/Ar/Kr/Xe)	g–t range	See product specs	Atmospheric concentration × ASU air throughput × rare gas recovery efficiency (~60%)
Total GAS output	71.9 t/day	287 t/day	Dominated by GAS-001 mixed syngas (31 t/day) and GAS-003 CO2 (15 t/day)

GAS product output:

ID	RC	Product	100 TPD	400 TPD	1,000 TPD	2,000 TPD
GAS-001	RC1	Mixed Gas	31.0 t/d	124 t/d	310 t/d	620 t/d
GAS-003	RC2	Carbon Dioxide, Industrial	15.0 t/d	60.0 t/d	150 t/d	300 t/d
GAS-004	RC2	Nitrogen, Industrial	6.25 t/d	25.0 t/d	62.5 t/d	125 t/d
GAS-005	RC2	Oxygen, Industrial	6.25 t/d	25.0 t/d	62.5 t/d	125 t/d
GAS-	R	High-Purity Nitrogen	6.25 t/d	25.0 t/d	62.5 t/d	125 t/d

006	C 3					
GAS-007	RC 3	High-Purity Oxygen	5.00 t/d	20.0 t/d	50.0 t/d	100 t/d
GAS-008	RC 3	Argon	0.050 t/d	0.200 t/d	0.500 t/d	1.00 t/d
GAS-016	RC 3	Pure Carbon Monoxide	0.500 t/d	2.00 t/d	5.00 t/d	10.0 t/d
GAS-017	RC 3	Beverage-Grade CO_2	1.00 t/d	4.00 t/d	10.0 t/d	20.0 t/d
GAS-010	RC 4	Specialty Gas Mixtures	0.500 t/d	2.00 t/d	5.00 t/d	10.0 t/d
GAS-011	RC 4	Neon	0.0010 t/d	0.0040 t/d	0.010 t/d	0.020 t/d
GAS-013	RC 5	Ultra-High Purity Nitrogen	0.050 t/d	0.200 t/d	0.500 t/d	1.00 t/d
GAS-014	RC 5	Xenon	8.0e-6 t/d	0.0e+0 t/d	1.0e-4 t/d	2.0e-4 t/d
GAS-015	RC 5	Krypton	4.0e-5 t/d	2.0e-4 t/d	4.0e-4 t/d	8.0e-4 t/d
TOTAL		14 products	71.9 t/d	287 t/d	719 t/d	1,437 t/d

2.5 ARM — Aromatics Cascade

The ARM family processes the liquid condensate from the MCR output — the aromatic hydrocarbon fraction of OmniCrude™. Mass flows are based on MCR liquid condensate yield and BTX/PAH split from published pyrolysis-gas chromatography literature for mixed organic feedstocks.

Parameter	@100 TPD	@400 TPD	Derivation
MCR liquid condensate (ARM input)	~19.95 t/day	~79.8 t/day	MCR liquid yield: ~10–15% of organic fraction input; ~20 t/day design-basis at 100 TPD
BTX fraction (benzene+toluene+xylenes)	~12.5 t/day	~50 t/day	BTX content of condensate: ~60–70% by mass (GC model; Py-GC/MS literature for mixed plastics + biomass)
Heavy aromatics (naphthalene+PAHs)	~7.5 t/day	~30 t/day	Heavy fraction: ~30–40% of condensate; naphthalene dominant
ARM product cascade total	20.0 t/day	79.8 t/day	Sum of all ARM distillation and reaction products; cascade products partially overlap

ARM product output:

ID	RC	Product	100 TPD	400 TPD	1,000 TPD	2,000 TPD
ARM-001	RC2	Mixed Aromatics	1.25 t/d	5.00 t/d	12.5 t/d	25.0 t/d
ARM-002	RC2	BTX Mixture	1.25 t/d	5.00 t/d	12.5 t/d	25.0 t/d
ARM-003	RC3	Benzene	3.75 t/d	15.0 t/d	37.5 t/d	75.0 t/d
ARM-004	RC3	Toluene	3.75 t/d	15.0 t/d	37.5 t/d	75.0 t/d
ARM-005	RC3	Mixed Xylenes	2.75 t/d	11.0 t/d	27.5 t/d	55.0 t/d
ARM-013	RC3	Aromatic Marine Fuel Blendstock	1.00 t/d	4.00 t/d	10.0 t/d	20.0 t/d
ARM-006	RC4	para-Xylene	2.00 t/d	8.00 t/d	20.0 t/d	40.0 t/d
ARM-007	RC4	Styrene	1.50 t/d	6.00 t/d	15.0 t/d	30.0 t/d
ARM-008	RC4	Phenol	1.25 t/d	5.00 t/d	12.5 t/d	25.0 t/d

ARM-009	RC4	Naphthalene	1.00 t/d	4.00 t/d	10.0 t/d	20.0 t/d
ARM-014	RC4	Recovered Polystyrene Monomer	0.400 t/d	1.60 t/d	4.00 t/d	8.00 t/d
ARM-010	RC5	Anthracene	0.050 t/d	0.200 t/d	0.500 t/d	1.00 t/d
ARM-011	RC5	Pyrene	0.0050 t/d	0.020 t/d	0.050 t/d	0.100 t/d
TOTAL		13 products	20.0 t/d	79.8 t/d	200 t/d	399 t/d

ARM products are derived from the OmniCrude™ aromatic liquid phase. The specific condensate composition is proprietary process information (Room 3). This table documents the output mass flows only.

2.6 MIN — Mineral Cascade

The MIN family recovers the inorganic mineral fraction from the manufacturing feedstock. MIN-004 PCC is a special case — it adds external mass (calcium hydroxide + captured CO2) and is therefore the only Carbotura product whose output mass exceeds its feedstock-derived input.

Parameter	@100 TPD	@400 TPD	Derivation
Manufacturing feedstock inorganic mineral content	~10–15 t/day	~40–60 t/day	Inorganic non-metallic non-glass fraction: ~10–15% of feedstock (concrete, ceramic, mineral dust)
MIN-001 Mineral Aggregate (primary)	~10 t/day	~40 t/day	Bulk mineral fraction recovery: ~90% of inorganic content; ~10 t/day design-basis
MIN-002 Pozzolanic SCM (from MIN-001)	~5 t/day	~20 t/day	Classification and activation: ~50% of MIN-001 suitable for pozzolanic grade
MIN-004 PCC (CO2 + Ca(OH)2 → CaCO3)	~0.5 t/day	~2 t/day	CO2 feed: ~15 t/day GAS-003 × small fraction; Ca(OH)2 input: 0.74 t per tonne CaCO3; stoichiometric yield
Ca(OH)2 external input for MIN-004	~0.37 t/day	~1.5 t/day	Purchased lime: 0.74 kg Ca(OH)2 per kg CaCO3 (stoichiometric). This is an external input to the facility.
Total MIN output	17.4 t/day	69.4 t/day	Sum of MIN products; MIN-004 adds external Ca(OH)2 mass

MIN product output:

ID	RC	Product	100 TPD	400 TPD	1,000 TPD	2,000 TPD
MIN-001	RC1	Mineral Aggregate	10.0 t/d	40.0 t/d	100 t/d	200 t/d
MIN-002	RC2	Pozzolanic SCM Powder	5.00 t/d	20.0 t/d	50.0 t/d	100 t/d
MIN-003	RC3	Geopolymer Precursor	1.50 t/d	6.00 t/d	15.0 t/d	30.0 t/d
MIN-004	RC3	Precipitated Calcium Carbonate	0.500 t/d	2.00 t/d	5.00 t/d	10.0 t/d
MIN-005	RC4	Specialty Mineral Filler	0.300 t/d	1.20 t/d	3.00 t/d	6.00 t/d
MIN-006	RC5	Low-Activation Aggregate	0.050 t/d	0.200 t/d	0.500 t/d	1.00 t/d
TOTAL		6 products	17.4 t/d	69.4 t/d	174 t/d	347 t/d

2.7 WTR — Water Cascade

The WTR family processes all facility process water streams into a cascade of increasingly pure water products. Water inputs include feedstock moisture (~20–25% of feedstock mass), reagent water from MTL hydrometallurgical modules, and makeup water. The facility is designed for Near-Zero Liquid Discharge (NLD).

Parameter	@100 TPD	@400 TPD	Derivation
Feedstock moisture input	~20–25 t/day	~80–100 t/day	Feedstock moisture content: 20–25% w/w (typical for mixed manufacturing feedstock; measured quarterly)
Reagent water (MTL hydrometallurgy)	~5–10 t/day	~20–40 t/day	Hydromet water consumption per module: ~3–5 kg water per kg metal processed; estimate from published hydromet LCAs
Makeup water (cooling, process)	~5–8 t/day	~20–32 t/day	Cooling tower evaporation + process losses; estimate from facility design calculations
WTR-001 Treated Wastewater (lowest grade)	~28.75 t/day	~115 t/day	Primary water output; primarily internal cascade feed; NPDES discharge fraction <5%
NPDES discharge (designed)	<1.4 t/day	<5.75 t/day	<5% of WTR-001 output; treated to permit standard
Total WTR saleable products	60.0 t/day	240 t/day	Sum of all WTR product grades; cascade products overlap (WTR-003 produced from WTR-001 etc.)

WTR product output:

ID	RC	Product	100 TPD	400 TPD	1,000 TPD	2,000 TPD
WTR-001	RC1	Treated Wastewater	28.8 t/d	115 t/d	288 t/d	575 t/d
WTR-002	RC1	Gray Water	7.50 t/d	30.0 t/d	75.0 t/d	150 t/d
WTR-003	RC2	Filtered Water	2.50 t/d	10.0 t/d	25.0 t/d	50.0 t/d
WTR-004	RC3	Softened Water	7.50 t/d	30.0 t/d	75.0 t/d	150 t/d
WTR-005	RC3	Distilled Water	2.50 t/d	10.0 t/d	25.0 t/d	50.0 t/d
WTR-006	RC3	Purified Water (USP)	2.50 t/d	10.0 t/d	25.0 t/d	50.0 t/d
WTR-	R	Deionized Water	3.75 t/d	15.0 t/d	37.5 t/d	75.0 t/d

007	C 4					
WTR-008	RC 4	Semiconductor Grade Water	2.50 t/d	10.0 t/d	25.0 t/d	50.0 t/d
WTR-009	RC 5	Pharmaceutical Grade Water	1.25 t/d	5.00 t/d	12.5 t/d	25.0 t/d
WTR-010	RC 5	Ultra-Pure Water	1.25 t/d	5.00 t/d	12.5 t/d	25.0 t/d
TOTAL		10 products	60.0 t/d	240 t/d	600 t/d	1,200 t/d

2.8 WTR-FC — Fuel Cell Water Cascade

WTR-FC products are produced exclusively from PEM fuel cell exhaust water — the stoichiometric product of hydrogen oxidation (2H2 + O2 → 2H2O). This stream is inherently ultra-high purity (no dissolved minerals) and requires minimal polishing to reach semiconductor and pharmaceutical-grade specifications.

Parameter	@100 TPD	@400 TPD	Derivation
H2 throughput to PEM stack	~2–4 t/day H2	~8–16 t/day H2	H2 yield from three internal recovery points; all directed to PEM — none sold
O2 consumed by PEM (from ASU)	~16–32 t/day O2	~64–128 t/day O2	PEM stoichiometry: 8 kg O2 per kg H2; O2 supplied from internal ASU output
PEM water output (2H2 + O2 → 2H2O)	~18–36 t/day H2O	~72–144 t/day H2O	PEM stoichiometry: 9 kg H2O per kg H2; all captured from cathode exhaust
WTR-FC-001 Industrial DI (primary)	~25 t/day	~100 t/day	Majority of PEM water at design-basis; some evaporative/process losses before capture
WTR-FC-002 Semiconductor Grade	~6 t/day	~24 t/day	Polished fraction of WTR-FC-001; ~24% of WTR-FC-001 upgraded to semiconductor grade
WTR-FC-003 Ultra-Pure	~3 t/day	~12 t/day	Final polished fraction; ~12% of WTR-FC-001 upgraded to ASTM Type I
Total WTR-FC output	34.0 t/day	136 t/day	Design-basis 34 t/day at 100 TPD; scales linearly with H2 throughput

WTR-FC product output:

ID	RC	Product	100 TPD	400 TPD	1,000 TPD	2,000 TPD
WTR-FC-001	RC 3	FC Water — Industrial DI	25.0 t/d	100 t/d	250 t/d	500 t/d

WTR-FC-002	RC4	FC Water — Semiconductor	6.00 t/d	24.0 t/d	60.0 t/d	120 t/d
WTR-FC-003	RC5	FC Water — Ultra-Pure	3.00 t/d	12.0 t/d	30.0 t/d	60.0 t/d
TOTAL		3 products	34.0 t/d	136 t/d	340 t/d	680 t/d

3. Verification Requirements

The following measurements are required during commissioning and Year 1 operations to move these design-basis mass balance figures to verified status. Verified mass balance is the prerequisite for the certified ISO 14044 LCA (LCA-001 Section 9).

Flow	Measurement Method	Accuracy Required	Timeline	Closes Claim
Manufacturing feedstock input mass	Calibrated belt scale at intake, continuous	±0.5%	From COD	FAC-004
CRB family total output mass	Calibrated mass balance per CRB module exit, per batch	±1%	From COD	FAC-004, ENV-001
MTL family total output mass	Calibrated mass balance per MTL stream, per shift	±1%	From COD	FAC-004
GLS family total output mass	Mass balance at GLS module outputs	±2%	From COD	FAC-004
GAS family output volumes/masses	Calibrated flow meters on all GAS product lines	±1%	From COD	FAC-004
ARM family output mass	Calibrated mass balance at ARM module exits	±1%	From COD	FAC-004
MIN family output mass	Calibrated mass balance per MIN module	±1%	From COD	FAC-004
WTR output mass + NPDES discharge	Calibrated flow meters + NPDES meter	±2%	From COD	FAC-005
WTR-FC water production	Mass balance: H2 input × 9 kg/kg, verified by cathode output meter	±2%	From COD	FAC-003
H2 throughput to PEM (internal)	Calibrated H2 flow meter at PSA outlet to PEM	±1%	From COD	FAC-001, FAC-003
ASU air input + N2/O2/Ar output	ASU instrumentation (standard industrial specification)	±1%	From COD	FAC-004 (GAS balance)
Annual mass balance closure	Annual reconciliation: Σ inputs = Σ outputs ± measured losses	±2% on closure	Annual	FAC-004 (certified)

Mass Balance Closure Acceptance Criterion

Mass balance closure is defined as: (Σ all product outputs + measured losses) / (Σ all inputs) = 100% ± 2%. If closure deviates by more than ±2%, the discrepancy must be identified and resolved before the certified LCA proceeds. Closure verification is a commissioning acceptance criterion.

4. Energy Balance Summary

The energy balance is a companion to the mass balance. It documents the designed energy inputs and outputs for the facility, confirming the Island Mode autonomy claim (FAC-001/FAC-002).

Energy Flow	@100 TPD	@400 TPD	Derivation
H2 throughput to PEM (internal fuel)	~2–4 t/day H2 = ~240–480 GJ/day LHV	~960–1,920 GJ/day	H2 LHV = 120 MJ/kg; H2 mass × 120
PEM electrical output (to facility)	~60–100 MWe (continuous)	~240–400 MWe	PEM fuel cell efficiency: ~50–60% electrical; ~2–4 t H2/day × 120 MJ/kg × 55% eff. = ~66–132 MW
PEM thermal output (process heat recovery)	~40–70 MWth	~160–280 MWth	PEM thermal: ~40% of H2 LHV at design operating temperature; recovered for process heating
Grid electricity consumption	0 MWe	0 MWe	No grid connection — structurally zero Scope 2
MCR microwave energy input	~20–40 MWe (from PEM output)	~80–160 MWe	MCR primary energy consumer; microwave energy input from internal PEM electricity
CRB graphitisation energy (CRB-RC3-HPG)	~10–20 MWe (from PEM output)	~40–80 MWe	Electromagnetic graphitisation at 3,000°C; largest single process energy consumer after MCR
ASU cryogenic separation energy	~5–10 MWe (from PEM output)	~20–40 MWe	Standard ASU specific energy: ~0.3–0.5 kWh/Nm³ N2 at the design separation volumes
Remaining process modules (MTL, GLS, etc.)	~15–30 MWe (from PEM output)	~60–120 MWe	All other process modules combined; MTL hydrometallurgy is the secondary energy consumer

The energy balance figures are design-basis estimates. The MCR and CRB graphitisation modules are the two largest energy consumers and have the highest uncertainty (±20%). Smart meters on these two modules are the highest-priority energy monitoring instrumentation at commissioning.

5. Document Control

Document ID	LCA-002
Title	Mass Balance Framework v1.0 — ACM Manufacturing Center
Version	Rev 1.0 — Design Basis
Classification	Room 2 — Technical Portal — NDA Required
Claims supported	FAC-004 (Zero Solid Waste); FAC-001/FAC-003 (Energy Autonomy / Net Water Producer); ENV-001 (Product Carbon Intensity allocation factors)
Related documents	FEP-001 v1.0; CR-001 v1.0; LCA-001 v1.0; CMD-001 v1.0
Verification	Section 3 defines commissioning measurements required to move from design-basis to verified status. Certified mass balance is required before ISO 14044 certified LCA proceeds.
Next revision	Rev 2.0 post-commissioning incorporating measured flow data

C O N F I D E N T I A L I T Y N O T I C E

This document is classified Room 2 — Technical Portal. The mass balance figures, energy balance estimates, and feedstock composition assumptions herein are proprietary engineering data. Not for external distribution without NDA.