Athena Sustainable Materials Institute

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LCA Project Report:

A North American Industry Average Cradle-to-Grave Life Cycle Assessment of ½" Lightweight and ⅝" Type X Conventional Gypsum Boards

Prepared for:
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By:

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EPD Program Operator: Smart EPD

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This final report is an abridged version of the original report whereby possible confidential information has been removed to protect the GA and its members

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General Summary

This life cycle assessment (LCA) report presents industry average results for ½" Lightweight (Regular core) and ⅝" Type X conventional (Type X core) gypsum boards as produced by Gypsum Association members in the North America. The LCA has been conducted to support a Type III Environmental Product Declaration (EPD) for ½" Lightweight and ⅝" Type X gypsum board conforming to ASTM C1396, Standard Specification for Gypsum Board (1). Specifically, this industry average LCA background report (named the "Project Report" in ISO 21930:2017 (2)) has been conducted in conformance with ISO 14040/44 standards (3), (4), and according to the requirements of ISO 21930:2017 (2), Smart EPD Part A Product Category Rules for Building and Construction Products and Services (5), Smart EPD Part B Product Category Rules for Gypsum Panels (6), and Smart EPD General Program Instructions (7). The underlying LCA report for EPD development purposes was commissioned by the Gypsum Association and its members, and is verified by Smart EPD to conform to the requirements of ISO 14040 (3), 14044 (4), 14025 (8), and 21930 (2).

General Summary	
EPD Commissioner	**Gypsum Association (GA)** 962 Wayne Ave, Suite 620 Silver Spring, MD 20910 The GA is a not-for-profit trade association founded in 1930. Any firm or corporation established in the business of calcining gypsum and manufacturing gypsum board in accordance with ASTM C 1396 in the U.S., Canada or Mexico is eligible for membership. The GA is the technical center for the application, finishing, and overall use of gypsum panels. The vision of the GA is to ensure a future where gypsum products are recognized and relied upon as being essential to the health, safety, comfort, sustainability and resilience of our buildings and quality of life. The mission of the GA is to promote the use of gypsum products while advancing the development, growth, and general welfare of the gypsum product industry on behalf of its member companies. The majority of GA member companies provided LCI and meta-data for the 2024 reference year. *The owner of the declaration is liable for the underlying information and evidence.*

GA Member Companies Corporate Locations	
	American Gypsum Company LLC 5960 Berkshire Lane, Suite 800 Dallas, TX 75225, USA Member Link (URL): https://www.americangypsum.com/
	Cabot Gypsum Company 521 Ferdinand Boulevard Dieppe, New Brunswick E1A 7G1, Canada Member Link (URL): https://cabotgypsum.com/
	CertainTeed Gypsum, Inc. CertainTeed Gypsum Canada, Inc. 20 Moores Road Malvern, PA 19355, USA Member Link (URL): https://www.certainteed.com/
	Georgia-Pacific Gypsum LLC 133 Peachtree Street NE Atlanta, GA 30303, USA Member Link (URL): https://www.gp.com/
	National Gypsum Company 2001 Rexford Road Charlotte, NC 28211, USA Member Link (URL): https://www.nationalgypsum.com/
	PABCO Gypsum 10811 International Drive Rancho Cordova, CA 95670, USA Member Link (URL) https://pabcogypsum.com/
	Panel Rey Drywall Solutions 1310 Rayford Park Road, Suite 404 Spring, TX 77386, USA Member Link (URL) https://www.panelrey.com/
	United States Gypsum Company (USG) 550 West Adams Street Chicago, IL 60661-3676, USA Member Link (URL): https://www.usg.com/en-US Canadian Gypsum Company (CGC) Inc. 350 Burnhamthorpe Road West, 5th Floor Mississauga, ON L5B 3J1, Canada Member Link (URL) https://www.usg.com/en-CA

Product, Product Groups and Names	Gypsum Board
Product Category Rules (PCR)	Smart EPD (2025) Part A Product Category Rules for Building and Construction Products and Services, Version 1.2. Standard 1000. Published March 14, 2025. www.smartepd.com (5) Smart EPD Part B Product Category Rules for Gypsum Panels. Version 2.0. Standard 1000-004. Published February 24, 2025. www.smartepd.com. (6)
Certification Period	[DATE] – 5-year validity
Functional Unit	92.9 m^2 (1000 ft^2) of ½" (12.7mm) Lightweight and ⅝" (15.9mm) Type X conventional gypsum board with a RSL of 75 years.
SmartEPD Declaration Numbers	EPD [###]
EPD and Project Report Information	
Program Operator	Smart EPD
Declaration Holder	Gypsum Association (GA)

Declaration Type

A "cradle-to-grave" EPD for ½" Lightweight and ⅝" Type X conventional gypsum board manufactured by GA members. Activity stages or information modules covered include production, installation, use, and end-of-life (A1-C4). The declaration is intended for use in Business-to-Business (B-to-B) and Business-to-Consumer communication.

Markets of Applicability

North America

Product Applicability

Gypsum board products are used extensively in building construction and renovation as an enclosing surface for interior walls and ceilings providing a finishing surface as well as mold and fire resistance.

Content of the Declaration

This declaration follows *Section 9, EPD Content,* as documented in Smart EPD Part A and Part B PCRs (5), (6).

This EPD was independently verified by Smart EPD in accordance with ISO 14025, ISO 21930, and Smart EPD Part A & B PCRs: **Internal** **External** **X**	Smart EPD info@smartepd.com www.smartepd.com
The Project Report *Note that this Project Report is not part of the public communication (ISO 21930, 10.1).*	A North American Industry Average Cradle-to-Grave Life Cycle Assessment of ½" Lightweight and ⅝" Type X Conventional Gypsum Board. April 2026.
Prepared by Athena Sustainable Materials Institute	Athena Sustainable Materials Institute 280 Albert Street, Suite 404 Ottawa, Ontario, Canada K1P 5G8 info@athenasmi.org www.athenasmi.org
This EPD project report was independently verified to be in accordance with ISO 14025, ISO 14040/44, and ISO 21930 by:	Sveda Alanya Rosenbaum, PhD.
PCR Information	
Program Operator	Smart EPD
Reference PCR	Smart EPD (2025) Part A Product Category Rules for Building and Construction Products and Services, Version 1.2. Standard 1000. Published March 14, 2025. www.smartepd.com (5) Smart EPD Part B Product Category Rules for Gypsum Panels. Version 2.0. Standard 1000-004. Published February 24, 2025. www.smartepd.com. (6)
Date of issue	Part A PCR: March 14, 2025 Part B PCR: February 24, 2025

PCR review was conducted by:	Part A PCR: Jack Geibig (Chair) Terrie Boguski Hugues Imbeault-Tétreault Part B PCR: Jack Geibig (Chair) Michael Gardner Gaurav Das

Terms and definitions

ISO 14040:2006/Amd1:2020 and ISO 14044:2006/Amd1:2017/Amd2:2020 – Clause 3 Terms and definitions:

Allocation: Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.

Comparative assertion: Environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function.

Life cycle: Consecutive and interlinked stages, from raw material acquisition or generation from natural resources to final disposal.

Life Cycle Assessment (LCA): Compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle.

Life Cycle Impact Assessment (LCIA): Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life Cycle Interpretation: Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

Life Cycle Inventory (LCI): Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Product system: Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product.

System boundary: Boundary based on a set of criteria specifying which unit processes are part of the system under study.

Sensitivity check: Process to determine whether the information obtained from a sensitivity analysis is relevant for reaching conclusions and for giving recommendations.

Uncertainty analysis: Systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty, and data variability.

Note: Either ranges or probability distributions are used to determine the uncertainty in the results.

ISO 14021:2016 (9) – *Clause 3 Terms and definitions:*

Recovered material: Material that would have otherwise been disposed of as waste or used for energy recovery but has instead been collected and recovered as a material input, in lieu of new primary material, for a recycling or a manufacturing process.

Pre-consumer material: Material diverted from the waste stream during a manufacturing process. Excluded is reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.

Post-consumer material: Material generated by households or by commercial, industrial, and institutional facilities in their role as end-users of the product that can no longer be used for its intended purpose. This includes returns of material from the distribution chain.

ISO 14025:2006 – Clause 3 Terms and definitions:

Type III Environmental Product Declaration (EPD): Providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information
Note 1 the predetermined parameters are based on the ISO 14040 series of standards.
Note 2 the additional environmental information may be quantitative or qualitative.

Product Category Rules (PCR): Set of specific rules, requirements, and guidelines for developing Type III environmental declarations for one or more product categories.

ISO 21930:2017 – Clause 3 Terms and definitions:

Average data: Data based on a fully representative sample for a construction product of construction service, provided by one or more suppliers, either from their multiple plants or based on multiple similar construction products of the supplier(s).

By-product: Co-product from a process that is *incidental or not intentionally* produced and which cannot be avoided.

Co-product: Any of one or more products from the same unit process, but which is not the object of the assessment.

Functional Unit: Quantified performance of a product system for a construction product or construction service for use as a reference unit in an EPD based on LCA that includes all stages of the life cycle.

Information module: Compilation of data to be used as a basis for an EPD, covering a unit process or a combination of unit processes that are part of the life cycle of a product.

Life cycle: All consecutive and interlinked stages in the life of the object under consideration.
Note 1: For consideration of environmental impacts and environmental aspects, the life cycle compromises all stages, from raw material acquisition or generation from natural resources to end-of-life.

Product category: Group of construction products that can fulfill equivalent functions.

Smart EPD Part B PCR for Gypsum Panels – Section 3 Terms and definitions:

Part A/Core PCR: A core PCR, also referred to as Part A PCR, provides the foundational rules and requirements for conducting a Life Cycle Assessment (LCA) and developing Environmental Product Declarations (EPDs) across a broad category of products or services. It sets the overarching framework that applies to multiple product categories, ensuring consistency and standardization in the methodology used for LCA and EPA creation.

LCA Project Report: An LCA Project Report is a comprehensive document that details the methodology, data, and results of a Life Cycle Assessment (LCA) conducted for a product or service, particularly in the context of developing an Environmental Product Declaration (EPD) according to a Product Category Rule (PCR). An LCA Project Report is the supporting methodology report that conforms to ISO 14040, 14044, 14025, 21930 and the applicable PCR and provides the necessary documentation to verify the LCI, LCIA and additional environmental information reported in an EPD.

Part B/Sub-category PCR: A Part B PCR is a product-specific document that complements the Core or Part A PCR. It provides detailed, category-specific rules and requirements for conducting Life Cycle Assessments (LCAs) and developing Environmental Product Declarations (EPDs) for a particular product or service category. While the Part A PCR establishes general guidelines applicable across various product categories, the Part B PCR tailors these guidelines to the unique characteristics of a specific product group.

Calcination: A thermal treatment process in which a carbonate material, such as limestone (calcium carbonate, $CaCO3$), is heated to a high temperature in the absence of air or in a controlled atmosphere. This process causes the material to undergo a chemical transformation. In the context of industrial processes, calcination is specifically associated with the decomposition of calcium carbonate into calcium oxide (CaO, or quicklime) and carbon dioxide ($CO2$) gas.

Calcination (gypsum): The process of heating gypsum to remove water, converting it into a usable form of plaster (ASTM C22 – C22M) (10).

Flue gas desulfurization: A process to remove sulfur dioxide from exhaust flue gases, commonly used in power plants; produces synthetic gypsum as a byproduct.

Gypsum board: A type of gypsum panel product consisting of a non-combustible core primarily of gypsum with paper surfacing (ASTM C11 – 24) (11).

Gypsum panels: The general name for a family of sheet products consisting essentially of gypsum (ASTM C11 – 24) (11).

Joint compound: A plaster-like material used to fill and smooth joints between gypsum boards (ASTM C475 – C475M) (12).

Joint tape: A tape used in conjunction with joint compound to cover seams between gypsum boards (ASTM C475 – C475M) (12).

Joint treatment system: A system involving the application of joint tape and joint compound to cover the joints between gypsum board panels, creating a smooth surface for finishing (ASTM C475 – C475M) (12).

Paper-faced gypsum board: Gypsum board with paper facing on both sides, commonly used for walls and ceilings (ASTM C1396 – C1396M) (1).

Acronyms and abbreviations

ADP_f	Abiotic depletion potential for fossil resources
AP	Acidification potential
Athena	Athena Sustainable Materials Institute
ASTM	American Society for Testing and Materials
B2B	Business-to-business
BD+C	Building Design and Construction, LEED
CFC-11	Trichlorofluoromethane
CO_2	Carbon dioxide
CRU	Components for re-use
D	Direct (the source of data)
E	Estimated (the source of data)
EE	Recovered energy exported from the product system
EP	Eutrophication potential
EPD	Environmental product declaration
FFD	Fossil fuel depletion
FW	Consumption of fresh water
GA	Gypsum Association
GB	Gypsum board
GHG	Greenhouse gas
GWP 100	Global warming potential, 100 years' time horizon
HLRW	High-level radioactive waste, conditioned, to final repository
HWD	Hazardous waste disposed
I	Indirect (the source of data)
ID+C	Interior Design and Construction, LEED
ILLRW	Intermediate- and low-level radioactive waste, conditioned, to final repository
IPCC	International Panel on Climate Change
ISO	International Organization for Standardization
kg	Kilogram
km	Kilometer
kWh	kilowatt hours
LCA	Life cycle assessment
LCI	Life cycle inventory

LCIA	Life cycle impact assessment
LHV	Lower heating value
MER	Materials for energy recovery
MJ	Mega joule
MR	Materials for recycling
N	Nitrogen
NCV	Net caloric value
ND	Neighborhood development
NHWD	Non-hazardous waste disposed
NMVOC	Non-methane volatile organic compounds
$NRPR_M$	Non-renewable primary energy carrier used as material
$NRPR_E$	Non-renewable primary energy carrier used as energy
NRSF	Non-renewable secondary fuel
O_3	Ozone
ODP	Ozone depletion potential
RE	Recovered energy,
RPR_M	Renewable primary energy carrier used as material
RPR_E	Renewable primary energy carrier used as energy
RSF	Renewable secondary fuel
SFP	Smog formation potential
SM	Secondary material
SO_2	Sulfur dioxide
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
UNCPC	United Nations Central Product Classification
U.S. EPA	United States Environmental Protection Agency
VOCs	Volatile organic compounds

1. Introduction

The US Green Building Council's *Leadership in Energy and Environmental Design* (LEED) v4 and v5 green rating systems reward building projects across the LEED rating systems (BD + C, ID + C, ND, and Homes)[1] for selecting products from manufacturers who have disclosed and verified potential environmental impacts. The intent is to encourage the use of products and materials for which life-cycle information is available and that have environmentally, economically, and socially preferable life-cycle impacts.

The *life cycle assessment* (LCA) project report supports an *environmental product declaration* (EPD) for the production, installation, use, and end-of-life stages of gypsum board in North America, and as such, has a business-to-business (B2B) and business–to consumer (B2C) focus.

Life cycle assessment is an analytical tool used to comprehensively quantify and interpret the energy and material flows to and from the environment over the entire life cycle of a product, process, or service (3), (4). Environmental flows include emissions to air, water, and land, as well as the consumption of energy and material resources. By including the potential impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product. An EPD provides quantified environmental data using predetermined parameters, and where relevant, additional environmental information (8). The predetermined parameters are based on the ISO 14040 series of standards (3), (4), and ISO 21930 (2). The additional environmental information may be quantitative or qualitative.

The study demonstrates the Gypsum Association (GA) and its members' commitment to transparently sharing the environmental footprint of gypsum boards and in support of generating an environmental product declaration for ½" (12.7 mm) Lightweight and ⅝" (15.9 mm) Type X conventional gypsum board as produced in North America.

In support of the study, primary LCI data were collected for gypsum board production from 16 plants for the 2024 reference year. The gypsum board manufacturing plant study sample includes all GA member companies and represents about 25% of all establishments producing gypsum and about 30% of all gypsum board produced in North America. To ensure representativeness, the gypsum board manufacturing plant sample also considered the scale of operations, including a mix of small, medium, and large facilities, their geographic location, and their source of gypsum (adjacent quarry/mine, imported gypsum ore, and the use of domestic or imported flue gas desulfurized (FGD) synthetic gypsum)

[1] **LEED v5, MRc2: Reduce Embodied Carbon**

https://www.usgbc.org/scorm/introduction-leed-v5-design-and-construction

2. Study goals

2.1. Goals of the study

This is a sector-driven initiative by the Gypsum Association and its members to conduct a LCA to support the development of two Type III EPDs according to ISO 14025 (8), Smart EPD Part A & Part B PCRs (5), (6), and ISO 21930 (2). The EPDs cover ½" Lightweight and ⅝" Type X conventional gypsum board, as manufactured and distributed in North America by GA members.

2.2. Intended applications and audience

This LCA report is intended to support the development of EPDs for use in Business-to-Business (B-to-B) and Business-to-Consumer (B2C) communication. The intended audience for the EPDs include GA and its member companies, their suppliers, architects, engineers, specifying professionals, LCA practitioners and tool developers, academia, governmental organizations, policy makers, and other interested value chain parties who require reliable information on gypsum board products.

2.3. Comparative assertions

The industry average EPDs for ½" Lightweight and ⅝" Type X conventional gypsum board based on this Project Report (underlying LCA report for EPD development) are not a comparative assertion. Only EPDs prepared from cradle-to-grave life cycle results and based on the same function, Reference Service Life (RSL), quantified by the same functional unit, and meeting all the conditions for comparability listed in ISO 14025:2006 and ISO 21930:2017 can be used to compare between products.

EPDs are comparable only if they comply with ISO 21930, use the same sub-category PCR where applicable, include all relevant information modules, and are based on equivalent scenarios with respect to the context of construction works (2).

Per ISO 21930:2017, 10.1 (2), this project report is made available to the third-party verifier with the requirements of confidentiality as stated in ISO 14025 (8). This project report has been independently verified by Sveda Alanya Rosenbaum, PhD., in accordance with Smart EPD Part A and Part B PCRs (5), (6), ISO 14025 (8), ISO 14040/44 (3), (4), and the ISO 21930 requirements (2).

3. Product identification

3.1. Product applicability and relevant standards

Gypsum boards (UNCPC Code 314, UNSPSC 30161509) are manufactured to ASTM C1396 (1) and are designed to be used as an interior panel capable of supporting an array of finishes and demonstrating various performance characteristics. As specified in Smart EPD Part B PCR (6), *gypsum board* is defined as a type of gypsum panel product consisting of a noncombustible core primarily of gypsum with paper surfacing (11). Gypsum board products are used extensively in building construction and renovation as an enclosing surface for interior walls and ceilings providing a finishing surface as well as mold and fire resistance. Gypsum board is ubiquitous in its use and naming – also called *wallboard, drywall, plaster board, and gypsum panel.* The substrates consist of a noncombustible water-resistant gypsum core, sandwiched between two layers of paper. Typically, gypsum boards are manufactured in 4' wide and 8' length panels (4'x8') produced with a beveled edge and are compatible with most interior wall and ceiling applications. Gypsum boards may be available in other lengths and can vary in thickness and fire rating properties depending on the types of additives.

The focus of this industry average LCA study for EPD development is on two gypsum board products:

- ½" (12.7mm) Lightweight gypsum board (regular core); and
- ⅝" (15.9mm) Type X conventional gypsum board (Type X core).

As calculated, the mass-weighted average density of ⅝" Type X conventional gypsum board with 0% moisture content (MC) is 10.4 kg/m^2 with a minimum and maximum density of 9.2 kg/m^2 and 11.0 kg/m^2, respectively. It should be noted that ⅝" Type X conventional gypsum board (Type X core) does not cover ⅝" Mold and Moisture Resistant (MMR), paper faced abuse resistant, paper faced impact resistant (fiberglass mesh reinforcement embedded in the core) and paper faced plaster base gypsum board.

Similarly, the mass-weighted average density of ½" Lightweight gypsum board with 0% MC is 6.6 kg/m^2 with a minimum and maximum density of 5.5 kg/m^2 and 7.2 kg/m^2, respectively. ½" Lightweight gypsum board (regular core) does not cover ½" Mold and Moisture Resistant (MMR) or conventional weight board.

These two selected products represent around 80% of all gypsum board products manufactured in North America. ½" Lightweight gypsum board is more typically used in residential applications, while ⅝" Type X conventional gypsum board, having additional fire rating characteristics, is used primarily in commercial applications. It is noted that gypsum board manufacturing has undergone considerable innovation in terms of formulations and lightweighting. Lightweighting has been more pronounced in the manufacture of ½" gypsum board (regular core), which a number of manufacturers refer to as "lightweight" board as compared to "conventional" gypsum board. Figure 1 below provides a visual representation of gypsum board.



Figure 1: Gypsum board [Photo Courtesy: GA 2026]

3.2. Product Standards

Applicable product standards for gypsum board (UNCPC Code 314, UNSPSC 30161509) include:

- ASTM C11-24a – Standard Terminology Relating to Gypsum and Related Building Materials and Systems
- ASTM C22/C22M-00(2021) – Standard Specification for Gypsum
- ASTM C473-19 – Standard Test Methods for Physical Testing of Gypsum Panel Products
- ASTM C1396/C1396M-17 – Standard Specification for Gypsum Board
- ASTM D3273-16 – Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber
- ASTM E84-21a – Standard Test Method for Surface Burning Characteristics of Building Materials
- ASTM E119-20 – Standard Test Methods for Fire Tests of Building Construction and Materials
- ASTM E2921-22 – Standard Practice for Minimum Criteria for Comparing Whole Building Life Cycle Assessments for Use with Building Codes, Standards, and Rating Systems

As specified in Smart EPD Part B PCR, Section 9.3.2 (6), the following product specifications are applicable to gypsum board products covered in this industry-wide LCA and subsequent EPDs.

Table 1: Gypsum Panel Specifications

Label	Standard	
CSA/Masterformat	09 29 00	Gypsum Board
UNCPC	314	Boards and Panels
UNSPSC	30161509	Gypsum Board
Product class and standard	Gypsum Board (ASTM C1396)	
Product subcategory	Gypsum Wallboard Gypsum Ceiling Board	
Core type	Regular Type X	
Facer type	Paper	

3.3. Material Content

Table 2 below presents the mass-weighted average composition for 92.9 m^2 (one thousand square feet, 1 MSF) of ½" Lightweight and ⅝" Type X conventional gypsum boards by input material as derived from the GA member facilities LCI data for the 2024 reference year. The final weight of each board type includes chemically bound water.

Table 2: Mass-weighted average material content for 92.9 m^2 (1 MSF) of gypsum board by thickness

Inputs	½" Lightweight	⅝" Type X conventional	Units
Natural gypsum ore	228.18	513.99	kg
FGD synthetic gypsum	288.12	377.35	kg
Post-consumer gypsum[1)]	3.02	2.28	kg
Facing paper	21.34	20.04	kg
Backing paper	16.63	18.45	kg
Starch	4.04	3.50	kg
Vermiculite	0	0.46	kg
Fiberglass	0.25	2.34	kg
Potash	0.087	0.041	kg
Dextrose	0.65	0.68	kg
Dispersant	1.37	2.08	kg
Other Chemicals (retarders, foaming agents, etc.)	0.61	0.84	kg
Ball mill accelerator, BMA	4.07	1.86	kg
Edge Paste	0.24	0.20	kg
Sodium Trimetaphosphate	0.34	0.24	kg

Inputs	½" Lightweight	⅝" Type X conventional	Units
Emulsion (fluidizer)	0.73	1.72	kg
Siloxane	0.25	0.39	kg
Water	400.23	610.49	kg
Wet weight	952.68	1459.06	kg
Final weight, with MC	626	984	*kg*
Final MC	2.50	2.11	%
Final weight, with 0% MC	611	963	*kg*

Note:

[1)] Post-consumer gypsum includes gypsum board on-site construction off-cuts and recovered gypsum material collected from demolition sites.

[2)] Data are rounded to an appropriate number of significant digits (2 to 4).

The percent composition of ½" Lightweight and ⅝" Type X conventional gypsum board are provided in Table 3 below.

Table 3: Mass-weighted average percent composition of ½" Lightweight and ⅝" Type X conventional gypsum board

Material	½" Lightweight	⅝" Type X conventional
Gypsum core	94%	96%
Facing and backing paper	6%	4%

4. Scope of the study

4.1. Functional unit

The functional unit is defined as the quantified performance of a product system for a construction product or construction service for use as a reference unit in an EPD based on LCA that includes all stages of the life cycle (2). The functional unit is defined as 92.9 m^2 (1000 ft^2) of ½" (12.7mm) Lightweight and ⅝" (15.9mm) Type X conventional gypsum board with a product RSL of 75 years, as specified in Smart EPD Part B PCR for Gypsum Panel (6). The PCR also assumes a building estimated service life (ESL) of 75 years, which is consistent with the 75-year building service life identified in ASTM E2921 (2022, Section 6.1.1) and ASHRAE 189.1 (2020, Section 9.5.1.2).

Table 4: Functional unit definition

Name	½" Lightweight	⅝" Type X conventional	Units
Functional unit	92.9	92.9	m^2
Mass	611	963	kg
Thickness	12.7	15.9	mm
Core type	Regular	Type X	n/a
Product Reference Service Life (RSL)	75	75	years

Note:

[1)] Data are rounded to three significant digits.

4.2. System boundary

For this study, the boundary is "cradle-to-grave," which includes the Production (A1-A3), Construction (A4-A5), Use (B1-B7), and End-of-Life stages (C1-C4), as depicted in Figure 2. Optional supplementary module D is excluded from the system boundary.

Per ISO 21930, 7.1.7.1 (2), the information modules A1, A2, and A3 are based on the actual and representative data of the production process of the product. However, as soon as a construction product leaves the factory gate, the assessment shall be based on scenarios and assumptions. The scenarios and assumptions considered depend upon various details including location, type of transport, method of installation and construction, type of construction works, use, maintenance and repair, end-of-life treatment, and waste handling.

The scenarios and assumptions used for modelling the Construction, Use, and End-of-Life stages are outlined in Section 7.1.7 of Smart EPD Part B PCR (6), and documented in detail below.

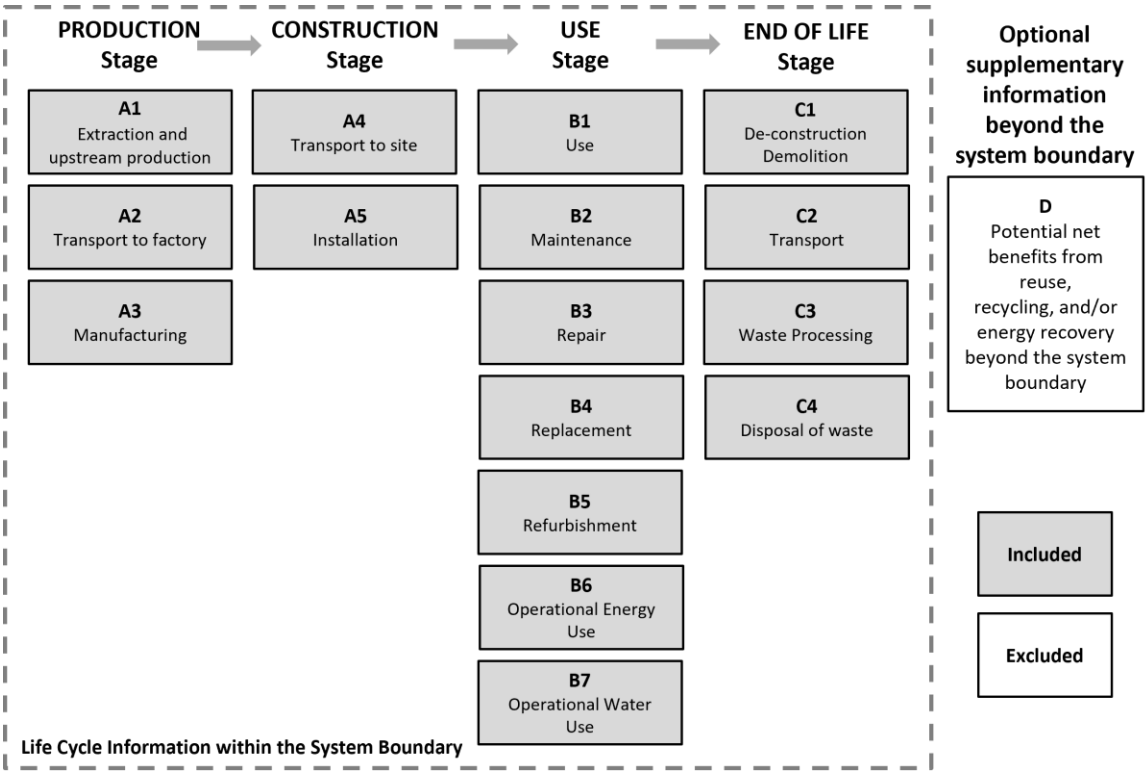


Figure 2: Common four life cycle stages and their information modules for construction products (2)

A1-A3, Production Stage

Per Smart EPD Part B PCR, Section 7.1.7.2 (2), the Production Stage includes the following processes:

A1, Extraction and upstream production

This information module includes:

- A1 extraction and processing of raw materials (natural gypsum ore) including the production of inputs where they are used (see Figure 3);
- A1, treatment of secondary materials used as input for manufacturing the product , but not including those processes that are part of the waste processing in the previous product system;
- A1, per Smart EPD Part B PCR 7.1.7.2.5 and 7.2.6 (6), *flue gas desulfurization (FGD) gypsum is used without an upstream burden, including all treatments necessary to make it usable as a product input such as sulfate conversion and dewatering.* As a result, the only burden associated with FGD gypsum is transportation to the manufacturing facility (Module A2), along with any drying of the FGD gypsum performed at the manufacturing facility (Module A3).
- A1, cradle-to-gate production of gypsum facing and backing papers (see Figure 4), and formulation materials (a.k.a, formulation additives);
- A1, cradle-to-gate generation of electricity used for extraction and processing of natural gypsum ore;
- A1, cradle-to-gate process fuel supply (diesel, gasoline, and propane) used for extraction and processing of natural gypsum ore, including on-site fuel combustion;
- A1, waste management from natural gypsum ore wastage including transport up to the disposal.

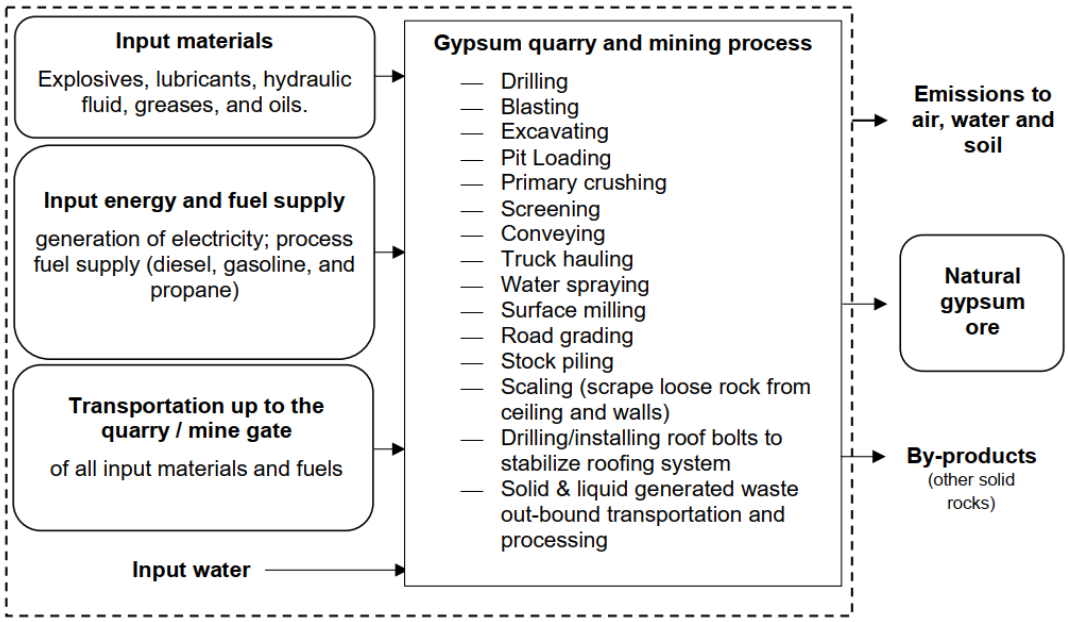


Figure 3 Cradle-to-gate system boundary of natural gypsum ore extraction, included in Module A1

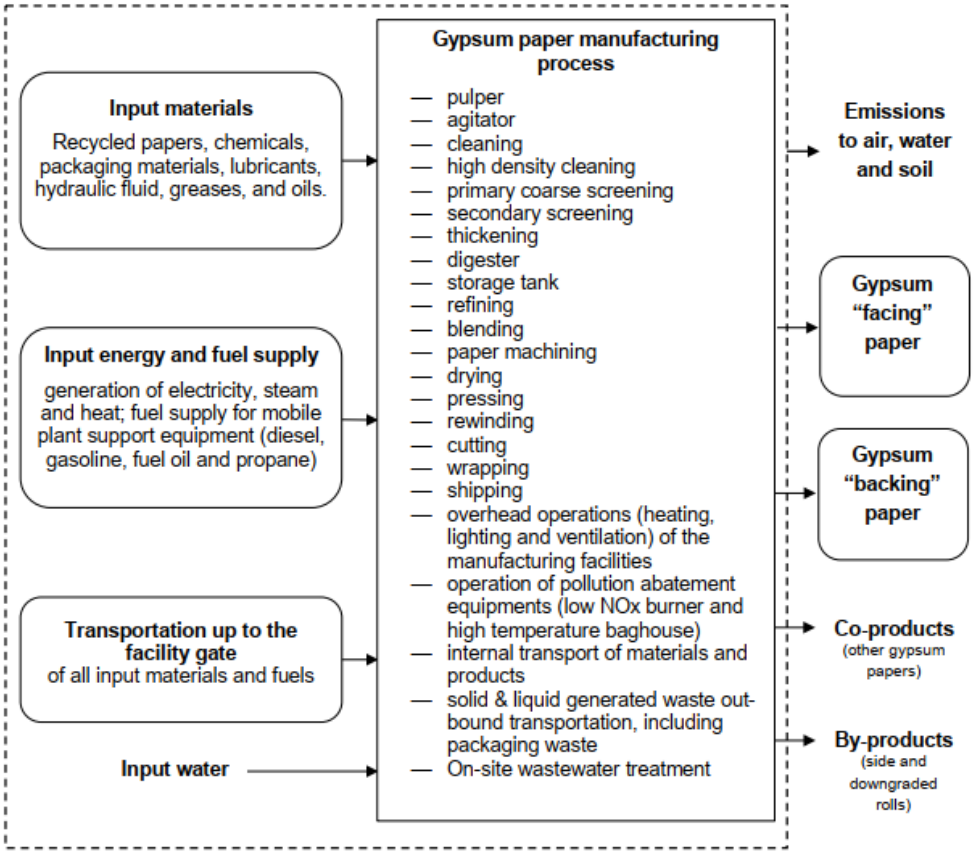


Figure 4 Cradle-to-gate system boundary of gypsum paper manufacturing, included in Module A1

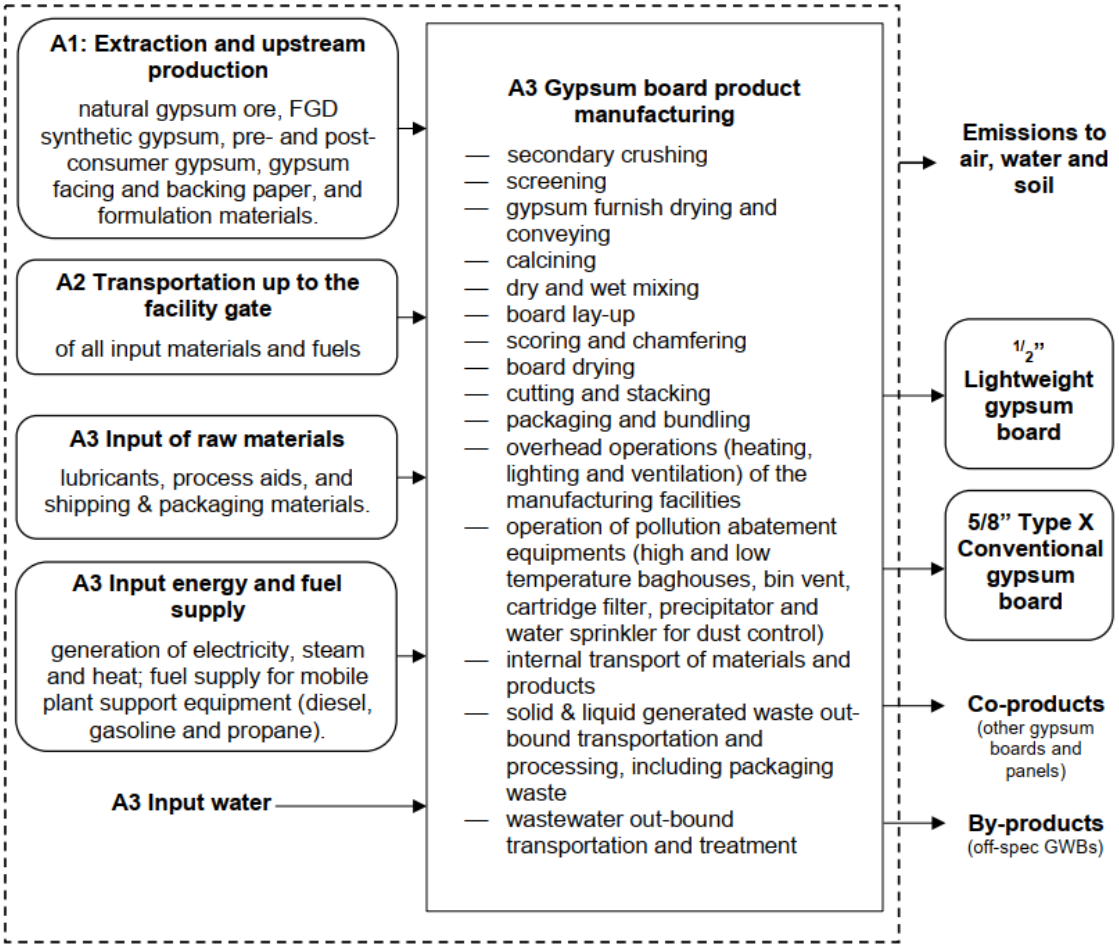


Figure 5 Production stage (modules A1 to A3) system boundary of gypsum board manufacturing

A2, Transport to factory

This information module includes mass-weighted average transportation data of all input materials (raw gypsum, synthetic gypsum, gypsum facing and backing papers, formulation materials, secondary, ancillary, and shipping & packaging materials) from extraction site or source to gypsum board manufacturing site, and including empty backhauls and transportation to interim distribution centers or terminals. In the absence of primary data for raw material transport, the default of 500 miles (800 km) transport to the manufacturing site and 300 miles (482 km) empty backhaul has been used as specified in Smart EPD Part B PCR Section 7.1.7.2.3 (6).

A3, Manufacturing

This information module includes:

- A3, cradle-to-gate production of *ancillary materials* (lubricants, process aids);
- A3, cradle-to-gate production of *shipping and packaging materials*;
- A3, any on-site treatment for *FGD synthetic gypsum*, such as additional drying;
- A3, any on-site treatment for *post-consumer gypsum* to make them usable as a product input, such as secondary crushing and/or screening;
- A3, cradle-to-gate generation of *electricity, steam and heat* used in manufacturing;
- A3, cradle-to-gate *fuel supply* for mobile plant support equipment (diesel, gasoline, and propane) used in manufacturing, including on-site fuel combustion;
- A3, manufacturing of gypsum board products and co-products (see Figure 5);
- A3, waste management from manufacturing packaging and manufacturing wastage including mass-weighted average transportation data up to the recycler or disposal.

A4-A5, Construction Stage

A4, Transportation to the construction site

This module includes both transportation from the factory gate to the central warehouse or intermediate distribution site (if relevant), as well as transport to the construction site. As specified in Smart EPD Part B PCR Section 7.1.7.3.1 (6), the following transportation modes and distances have been used:

- Distribution of gypsum panel products from the manufacturing gate to the distribution center gate is assumed to be 448 km (280 miles) by commercial tractor-trailer truck and 208 km (130 miles) by rail.
- Final transport from the distribution gate to the construction site is assumed to be 40 km (25 miles) by a single unit truck with an empty backhaul.

Table 5 summarizes the inputs and outputs used to model the Transport to construction site module (A4), in accordance with Smart EPD Part B PCR Section 9.4.2 (6).

Table 5: Transport to Building Site (A4)

Transport / Vehicle Type	Description of transport	Fuel Type	Fuel Efficiency, L/100km	Distance, km	Capacity utilization	Capacity utilization volume	Weight of products transported, kg
Tractor-trailer truck	From manufacturing site to DC	Diesel	35	448	Empty backhaul	=1	½" Lightweight: 611 kg 5/8" Type X: 963 kg
Rail	From manufacturing site to DC	Diesel	3	208		=1	
Single unit trick	From DC to construction site	Diesel	25	40	Empty backhaul	=1	

A5, Construction

This module follows the assumptions and scenarios documented in Smart EPD Part B PCR Section 7.1.7.3.2 (6), which are outlined below:

- The default on-site installation waste scenario for all gypsum panel products is 10% on a surface area basis of product.

The ancillary materials required for installation includes fasteners, joint tape, and joint compound. The amount of joint compound used during installation adheres to the PCR for joint compound, which specifies an installation scenario defined by a GA-214 Level 4 finish with the quantity adjusted for the measured shrinkage for a service life of 75 years. The amount of fasteners, joint tape, and joint compound usage is provided in Smart EPD Part B PCR Section 7.1.7.3.2 (6). Table 6 summarizes the inputs and outputs used to model the Installation module (A5), in accordance with Smart EPD Part B PCR Section 9.4.3 (6).

Table 6: Installation into the Building/Construction Work (A5)

Name	Quantity per Functional Unit ½" Lightweight	Quantity per Functional Unit ⅝" Type X	Unit
Installation scrap rate	10	10	%
Lightweight ready mixed joint compound, packaged in plastic pail	18.27	18.27	kg
Lightweight ready mixed joint compound, packaged in carton	9.13	9.13	kg
Conventional ready mixed joint compound, packaged in plastic pail	27.47	27.47	kg
Conventional ready mixed joint compound, packaged in carton	13.73	13.73	kg
Screws	2.70	2.70	kg
Joint tape	0.90	0.90	kg
Net freshwater consumption	0	0	m^3
Electricity consumption	0	0	kWh

Other energy carriers	0	0	kWh
Product loss per functional unit	61.1	96.3	kg
Total packaging waste materials resulting from on-site waste processing, sent to landfill	10.8	12.5	kg
Packaging – Plastics	0.12	0.17	kg
Packaging – Metals	1.37E-04	2.77E-05	kg
Packaging – Paper & Cardboard	0.30	0.37	kg
Packaging – Scrap Gypsum Board Used as Dunnage	10.4	12.0	kg
Total waste materials resulting from on-site waste processing, sent to landfill (sum of product loss and packaging waste)	71.9	108.8	kg
Biogenic carbon contained in packaging	0.50	0.60	kg CO_2

B1-B7, Use stage

As specified in Section 7.1.7.4 of Smart EPD Part B PCR (6), gypsum panels do not require maintenance, repair, replacement, or refurbishment over the course of the product's RSL of 75 years. Additionally, gypsum panels are assumed to have no operational energy or water use during the use phase of the product. As such, the Use Stage (B1-B7) potential environmental impacts are reported as zero ("0").

C1-C4, End-of-life stage

Per Smart EPD Part B PCR, Section 7.1.7.5 (6), the End-of-Life Stage includes the following processes:

C1, Deconstruction/demolition

Impacts from C1 are assumed to be zero ("0") based on manual labor using hand tools, as specified in Smart EPD Part B PCR Section 7.1.7.5 (6).

C2, End of life transportation

Impacts from the *C2, End-of-Life Transport* module include the transport of gypsum panel waste from the building to the landfill site. Assumptions for the waste transportation mode and distance are provided in Smart EPD Part B PCR, Section 7.1.7.5 (6), and documented below in Table 7.

C3, Waste processing

Smart EPD PCR Section 7.1.7.5 (6) assumes no gypsum panel waste goes to a waste processing facility prior to disposal in the landfill. Impacts from the *C3, Waste processing* module are assumed to be zero ("0"), as specified in Smart EPD Part B PCR Section 7.1.7.5 (6).

C4, Waste disposal

Smart EPD Part B PCR Section 7.1.7.5 (6) assumes gypsum waste is disposed of in an appropriate landfill. The burden of *Module C4* is modelled using appropriate secondary datasets, as documented in Annex B.

Table 7 summarizes the inputs and outputs used to model the End of Life Stage (C1-C4), in accordance with Smart EPD Part B PCR Section 9.4.6 (6).

Table 7: End of Life (C1-C4) Scenario Assumptions

Name			**Quantity per Functional Unit ½" Lightweight**	**Quantity per Functional Unit ⅝" Type X**	**Unit**
Demolition (Module C1)			0	0	kWh
Transport (Module C2)		Mass %	Distance		
	Truck	74.6%	44	44	km
	Rail	25.4%	469	469	km
Collection process			Collected with mixed construction waste		
Disposal of waste gypsum in inert material landfill (Module C4)			611	963	kg
Emissions of biogenic carbon (excluding packaging) (Module C4)			72.5	72.1	kg CO_2

4.3. Cut-off criteria

The cut-off criteria as specified in ISO 21930:2017, Section 7.1.8 (2) and Smart EPD Part A and Part B PCRs Section 7.1.8 (5), (6) were followed for this project report. All input/output data were collected and included in the LCI modelling (see Annexes A, B, and C). No substances with hazardous and toxic properties that pose a concern for human health and/or the environment as defined by the relevant legislation for US, Mexico, and Canada in Part A PCR Table 4[2] (5) were identified in the framework of this LCA. As specified by Smart EPD Part B PCR Section 8.4.1 (6), "The measurement of releases of dangerous substances from gypsum panels during the use and installation is not relevant to the scope of this Part B.".

Any plant specific data gaps for the 2024 reference year, such as hydraulic fluid, lubricants, and packaging materials have been filled in with primary plant specific data from previous years or industry average data. Safety Data Sheets (SDSs) were confidentially provided by GA plants per each chemical class (e.g., dispersants, retarder chemicals, etc.). Any data gaps in the SDS are filled in with two proxy generic LCI datasets, as appropriate as conservative assumptions: *Chemical, organic {GLO}| production | Cut-off, U*; *Chemical, inorganic {GLO}| production | Cut-off, U* – refer to Annex C, Table C1 for details.

As specified in Smart EPD Part B PCR Section 7.1.6 (6), this LCA study excludes the following processes:

- Capital goods and infrastructure;
- Human activity and personnel related activity (travel, furniture, office operations, and supplies; and
- Energy and water use related to company management and sales activities that may be located either with in the factory site or at another location.

[2] The following legislation references are used to define hazardous waste and hazardous substances, as defined by Smart EPD Part A PCR Section 7.1.9.5 (5):

US: Resource Conservation and Recovery Act (RCRA), Subtitle C

Canada: Transportation of Dangerous Goods (TDG) Regulations (SOR/2001-286); The Export and Import of Hazardous Waste and Hazardous Recyclable Material Regulations (SOR/2021-25), as originally adopted under the Canadian Environmental Protection Act (1999)

Mexico: Ecology Law (NOM-052-ECOL-1993) Annexes 2-5, with updated hazardous waste lists provided in NOM-052-SEMARNAT-2005

4.4. LCA software

The LCA model was developed using SimaPro v.10.2.0.1 2025 (https://simapro.com/) (13), which is an LCA software used by industry and academics in more than 80 countries for 25 years. SimaPro LCA software contains recognized databases such as ecoinvent and USLCI that provide LCI datasets for upstream, core, and downstream material and processes. SimaPro v10.2.0.1 2025 also contains the U.S. EPA TRACI v2.2 2024 LCIA methodology, Environmental Footprint (EF) reference package 3.1, CML-baseline version 4.8 2016 LCIA methodology, and the Cumulative Energy Demand, LHV (NCV) version 1.0 November 2018 which are used for this LCA study.

5. Life cycle inventory

5.1. Data collection, representativeness, sources, and calculations

Data collection was based on an initial survey of GA member facility operations. GA members operate 51 facilities in North America producing various gypsum panel products. Some facilities are 100% dedicated to the production of gypsum boards while others may produce paper faced as well as other gypsum panel products. In total, 16 facilities operated by 8 GA company members completed LCI data collection questionnaires representing a third of all GA member facilities producing gypsum board. GA member companies were notified via email on March 20, 2025 to request their involvement in the GA industry-average EPD prior to the project kick-off call with Athena Sustainable Materials Institute.

The study LCI data collected from the GA member companies was done with the expressed intent of attaining an acceptable representation of the US industry average technology mix. During the previous iteration of the GA's industry average LCA for gypsum board in 2019, the GA's LCA Working Task Group identified a representative sample of GB plants within its membership based on technical attributes, production scale, and geographic location to arrive at a *representative* sample of gypsum board manufacturing plants. Generally, the same industry sample has been relied on in this study to allow for accurate benchmarking of facility-specific data, although there were minor changes to participating facilities due to availability of primary data and ownership changes at participating plants. Described below is the GA's well-defined plant selection platform for inclusion in the industry-average study sample.

- In 2024, about 51 GB manufacturing plants were operating in North America.
- Of these, 16 plants were selected to adequately represent:
    - GA's membership production volume;
    - the scale of plant operations including *a mix of small, medium, and large* operations;
    - The geographical spread of the participating facilities included having *at least one plant* in *each US census region* included in the study.

- To approximate the gypsum source ratio, a mix of plants processing either natural gypsum rock or flue gas desulfurized (FGD) synthetically derived gypsum, or a blend of both these two major inputs was selected.
- A mix of plants using *locally derived natural gypsum* ore (adjacent quarry operation) versus imported natural gypsum ore transported by various modes and distances were included (natural gypsum ore imports include Mexico or Spain depending on plant location).
- A mix of plants that are dependent on local versus more distant USA sources, and imported sources of FGD synthetic gypsum were also included in the sample.

LCI data collection was based on a customized LCI survey for GA gypsum board manufacturing facilities. The LCI survey covered the following *primary data* for each facility for the 2024 reference year.

- Total manufactured products, and co-products (by-products);
- Main unit processes;
- Excluded processes;
- Pollution abatement equipment;
- Raw materials;
- Secondary materials (if applicable);
- Pre- and post-consumer materials (if applicable);
- Ancillary materials;
- Packaging materials;
- Electricity and fuel consumption;
- Water consumption (fresh and recycled);
- Inbound transportation distances and modes for all inputs;
- Emissions to air, water, and land (if and where applicable);
- Solid waste;
- Wastewater and other liquid waste;
- Waste outputs and their respective outbound transportation distances and modes.

Source of data is specified as (see Annex A, Tables A1 to A3):

Direct (D) based on measurements or purchasing/selling records of the surveyed facilities;

Indirect (I) based on calculations made by the personnel of the surveyed facilities;

Estimated (E) based on the industry average data and/or expert judgment;

Gate-to-gate primary LCI data from the previous iteration of the GA's industry average LCA for gypsum board (2017 reference year) has been relied upon for natural gypsum ore extraction (six quarries and one underground mining site) as well as the manufacture of gypsum facing and backing papers (three plants).

Annex A, Tables A1, A2 and A3 summarize the mass-weighted average LCI data for the three product systems – natural gypsum ore extraction, gypsum paper production, and gypsum board manufacturing. Annex A, Tables A4 to A7 show the transportation modes and mass-weighted average distance (in ton-mile or tkm) for all inputs and outputs per each product system. Transportation activities are included consistently in the respective life cycle modules (A1, A2, A3). Trucking is the primary mode of transport for all input/output flows followed by rail, barge, and ship.

Per Smart EPD Part B PCR (6) and ISO 21930 Section 5.3 (2), all facility specific LCI data have been weighted based on total annual production to calculate the mass-weighted average LCI profile for the natural gypsum ore, gypsum paper, and gypsum boards. Gypsum board manufacture data has been weighed using a mass-weighted average based on total annual production of each participating facility in accordance with Smart EPD Part B PCR, 5.3.2.1 (6). Table A9 summarizes the product packaging waste data at the installation site. All LCI data including meta-data were internally verified and benchmarked with 2017 plant specific and/or GA industry average LCI data for gypsum board production. The minimum and maximum range data are also calculated for each LCI flow to facilitate Monte Carlo uncertainty analysis (See Annex C) but are not reported due to confidentiality reasons.

The LCA study draws on appropriate LCI datasets, which are documented in Annexes A and B, provided by:

- Gypsum Association and its members on natural gypsum ore extraction, gypsum paper production, and gypsum board manufacturing; and
- North American and global LCI databases such as the USLCI 2024 Q3, US Electricity Baseline v6 (both available at https://www.lcacommons.gov/), and ecoinvent 3.11 allocation, cut-off by classification (http://www.ecoinvent.org/). These databases are included in the LCA software SimaPro v.10.2.0.1

Data calculation procedures follow ISO 14044 (4) and the Smart EPD Part A and Part B PCRs (5), (6). The same calculation procedures are applied throughout this LCA study. Per ISO 21930 Section 7.2.2 (2), when transforming the inputs and outputs of combustible material into inputs and outputs of energy, the *net calorific value (lower heating value)* of

fuels is applied according to scientifically based and accepted values specific to the combustible material. SI units are used for the LCA data and results, with conversions shown in Annex A Table A8, as necessary. Other units commonly used in the market are also included in addition to the required SI units (See Annex A, Tables A1 to A7).

5.2. Data quality requirements and assessments

Per Smart EPD Part A and Part B PCR and ISO 21930, Section 7.1.9 (2), (5), (6), appropriate activity and LCI primary and secondary data shall be used to model the gypsum board product system. LCI data should be as representative (technologically, geographically, and time-specific), complete, consistent, reproducible, and transparent as possible with regards to the goal and scope of the study (3), (4). A detailed description of background data and the data quality assessment regarding the ISO 14044 and ISO 21930 requirements is provided in Annex B, Tables B1 to B3. Data quality is assessed based on its representativeness (technology coverage, geographic coverage, time coverage), completeness, consistency, reproducibility, transparency, and uncertainty (see Table 8).

Table 8: Data quality requirements and assessments

Data Quality Requirements	Description
Technology Coverage	Data represents the prevailing technology in use in North America. Whenever available, for all upstream and core material and processes, North American typical or average industry LCI datasets were utilized (see Annex B, Table B1 to B3). *Technological representativeness is characterized as "high".*
Geographic Coverage	The geographic region considered is North America. The geographic coverage of all LCI databases and datasets is provided in Annex B. Whenever available, for all upstream and core material and processes, geographically specific LCI datasets were utilized. In cases where North American specific data were unavailable, European and Switzerland-specific ecoinvent datasets were preferred over Rest-of-World datasets as the European industry profile (in terms of process technology and manufacturing practices) more closely reflects North American conditions than Rest-of-World alternative. The geographic coverage of all LCI databases and datasets is provided in Annex B. *Geographical representativeness is characterized as "high".*

Data Quality Requirements	Description
Time Coverage	Activity data are representative as of 2024 (see Annex A, Tables A1 to A7). - Gypsum board manufacturing process- primary data collected from 16 facilities: reference year 2024 (12 months); - In-bound/ out-bound transportation data- primary data collected from 16 facilities: reference year 2024 (12 months); - Natural gypsum ore – primary data collected from six quarries and one gypsum ore underground mine: reference year 2017 (12 months); - Face and backing paper manufacturing- primary data collected from 3 facilities: reference year 2017 (12 months). - Generic data: the most appropriate LCI datasets were used as found in the US LCI Database, ecoinvent v.3.11 database for North America and global, 2025. *Temporal representativeness is characterized as "high".*
Completeness	All relevant, specific processes, including inputs (raw materials, energy and ancillary materials) and outputs (emissions and production volume) were considered and modeled to provide an industry average for ½" (12.7 mm) Lightweight and ⅝" (15.9 mm) Type X conventional gypsum board. The relevant background materials and processes were taken from the US LCI Q3 2024 Database , ecoinvent v 3.11 LCI database for US, and/or North America, and modeled in SimaPro software v.10.2.0.1, 2025. The completeness of the cradle-to-gate and cradle-to-grave process chains in terms of process steps is rigorously assessed for both gypsum boards and documented in Section 4.2.
Consistency	To ensure consistency, the LCI modeling of the production weighted input and output LCI data for the gypsum board product of interest used the same LCI modeling structure across the selected GA member facilities, which consisted of input raw, secondary, facing/backing, formulation, ancillary and packaging materials, energy flows, water resource inputs, product outputs, co-products, by-products, emissions to air, water and soil, and solid and liquid waste disposal. Crosschecks concerning the plausibility of mass and energy flows were continuously conducted. The LCA team conducted mass and energy balances at the facility level and selected process levels to maintain a high level of consistency.

Data Quality Requirements	Description
Reproducibility	Internal reproducibility is possible since the data and the models are stored and available in *GA Athena GB LCI database* developed in SimaPro, 2025. A high level of transparency is provided throughout the report as the mass-weighted average LCI profile is presented for each of the declared products as well as major upstream inputs. Key primary (manufacturer specific) and secondary (generic) LCI data sources are summarized in Annex B. External reproducibility is also possible as a high level of transparency is provided throughout the Project Report and LCI data and sources are summarized in Annexes A and B.
Transparency	Activity and background LCI datasets are transparently documented in the LCA report, including data sources (see Annexes A and B).
Uncertainty	A *sensitivity check* was conducted to assess the reliability of the EPD results and conclusions by determining how they are affected by uncertainties in the data or assumptions on calculation of LCIA and energy indicator results. The sensitivity check includes the results of the *sensitivity analysis* and *Monte Carlo uncertainty analysis* (see Section 7 and Annex C).

5.3. Allocation rules

As specified in Smart EPD Part B PCR Section 7.2.3 (6), allocation shall be based on the mass of gypsum panel products produced. Allocation related to transport shall be based on the mass of the transported products.

As specified in ISO 21930, Section 7.2.4 (2) consistent allocation procedures shall be uniformly applied to similar inputs and outputs of the system under consideration. For example, the approaches of allocation to co-products or to secondary materials crossing the system boundary between product systems should use the same procedure used for co-products or to secondary material flows entering the product system.

The GA gypsum board manufacturing facilities produce other co-products besides selected gypsum boards and as such allocation based on the mass of gypsum board products was necessary. Per ISO 21930 (2), a *co-product* is defined as any of one or more products from the same unit process, but which is not the object of the assessment. As a result, plant specific generic formulations for 1 MSF (92.9 m^2) of the two gypsum board products of interest were used to model and calculate the required input raw materials (both primary and secondary), facing/backing and formulation materials, and water input (see Table 2).

Per Smart EPD Part B PCR Section 7.2.3 (6), "*mass*" was used as the physical parameter for allocating flows between the products of interest and other co-products to calculate the input energy flows (electricity, natural gas, propane, etc.), shipping and packaging materials, lubricants, hydraulic fluid, greases, and oils, total water consumption, process emissions to air, water and land and waste flows. Similarly, plant specific generic

formulations for 1 MSF (92.9 m2) of gypsum paper and *mass* were used as the basis for allocating flows across products and *co-products* of gypsum paper manufacturing. LCI modeling accounts for the plant specific fabrication yields in accordance with ISO 14044, 4.3.4.2. Per Smart EPD Part B PCR Section 7.1.7.2.4, "*A3 Manufacturing shall include an assumption of 5% material loss unless product specific data are available and transparently reported in the project LCA report"*.

Per ISO 21930 (2), a *by-product* is defined as co-product from a process that is *incidental or not intentionally produced* and which cannot be avoided. No burden is allocated to any of the by-products of the selected product systems such as *off-spec gypsum boards (*used as dunnage/bunks/sleuters); *side rolls* (recycled back into the gypsum paper production, or sold out to other converters to make tubes and cores); *downgraded rolls* (used as paper fiber in the wallboard, or sold to other converters to make tubes and cores), or *other rocks* from gypsum ore extraction sites (sold to other industries), see Figure 3 through Figure 5 and Tables A1, A2 and A3.

Flue gas desulfurization (FGD) synthetic gypsum is a by-product of coal-fired power generation process – a result of SO_2 scrubbing of stack emissions enforced by the US EPA Clean Air Act – and a major raw material used in the production of gypsum board products (14), (15). Per Smart EPD Part B PCR 7.1.7.2.5 and 7.2.6 (6), "*flue gas desulfurization (FGD) gypsum is used without an upstream burden, including all treatments necessary to make it usable as a product input such as sulfate conversion and dewatering."* As a result, the only burden associated with FGD gypsum is transportation to the manufacturing facility (Module A2), along with any drying of the FGD gypsum performed at the manufacturing facility (Module A3).

5.4. Product manufacturing life cycle inventory

5.4.1. Natural Gypsum Ore Extraction

Natural gypsum ore (a.k.a, as *raw* or *crude* gypsum) is a relatively soft, rock-like mineral with a chemical formula of $CaSO_4 \times 2H_2O$ (calcium sulfate dihydrate). Gypsum rock is open pit quarried or mined underground, generally by drilling and blasting, then moved to a primary crusher on the quarry/mine site. The quarry process begins with the removal of overburden (earth) over the gypsum deposit. The gypsum rock is then drilled and blasted loose where it is then extracted and transported to the primary crusher. At the primary crusher the gypsum rock is reduced to approximately 2" (50 mm) to 5" (125 mm) or less in size. From here the crushed rock can be sent to the gypsum board manufacturing plant (trucked or belt conveyed) for secondary crushing. It may also be transported by ship, or truck to board manufacturing plants farther away.

Figure 3 shows all unit processes included in the *gate-to-gate* system boundaries for natural gypsum ore extraction. The production weighted average LCI data for natural gypsum ore extraction are reported in Annex A, Table A1. Inbound and outbound transportation data for natural gypsum ore extraction are provided in Annex A, Table A4.

5.4.2. Gypsum paper manufacturing

The input materials used for gypsum paper facings (known as facing and backing gypsum paper) are from recycled sources, either pre-consumer (known as post-industrial) or post-consumer. The recycled paper consists of Old Corrugated Container (OCC), Double-Lined Kraft Corrugated Cuttings (DLK), and mixed recovered papers (mixed waste papers/fly leaves, signature/white news blank, pub blank, coated fly etc.).

The manufacture of gypsum paper facings is similar to other paper making processes and starts with the recycled paper furnish being fed into a pulper, a large blender that disintegrates and dissolves the old paper into a pulp – a slurry of paper fibers. The paper slurry is also cleaned of various contaminants (e.g., bailing wire, staples, and glue) before it is fed into the paper-making machine. Two types of paper making equipment – rotating cylinders or a Fourdrinier flat wire machine, may be used to produce gypsum paper. A cylinder machine rotates a large drum through the pulp slurry vat. A wide felt belt passes over the top of the turning drum cylinder.

The cylinder pulls the pulp up and presses it against the bottom felt, where it sticks to form a single ply of paper – depending on the machine and slurry composition it can take as few as three to up to nine cylinder made plies pressed together to make a continuous sheet of gypsum board paper. The characteristics of the pulp entering the vats determine whether the system produces cream stock, often called "*ivory*", used for the face of the gypsum board or *gray stock*, which makes the backside paper of gypsum wallboard. The *gray stock* is derived exclusively from OCC, while the cream or *ivory* uses a combination of all recycled inputs for its pulp plies. Instead of a set of cylinder machines, the Fourdrinier uses two machines to make a two-ply paper with the same characteristics as the multi-ply cylinder made paper. The pulp slurry is systematically fed onto a continuously running wire screen (the Fourdrinier). As the screen moves forward, water drains from the pulp through the screen to create paper. One Fourdrinier machine makes the surface (top) ply, which may be cream or gray stock depending on the pulp mixture and the desired paper type. The second machine produces a gray (bottom) ply. From this point, both systems operate in the same way. In the press section, the paper plies are pressed together to squeeze out excess water. Next the paper enters a series of high temperature dryers where any remaining water is removed. The dry paper is then sent to a calendar stack, where different chemicals or treatments are applied (e.g., retention chemicals and sizing agents). The paper is then gathered on a roll, trimmed and packaged for shipment.

Figure 4 shows all unit processes and pollution abatement equipment included in the *gate-to-gate* system boundaries for gypsum paper manufacturing process. Both cylinder and Fourdrinier production methods were represented in the study facility sample and all three plants produced both *ivory* (3, 6 and 7-base layers) and *gray* stock gypsum papers, made 100% of OCC (3, 6 and 7-base layers). The production weighted average LCI data for gypsum paper production (face and backing paper) are reported in Annex A, Table A2.

Inbound and outbound transportation data for gypsum paper production are provided in Annex A, Table A5.

5.4.3. Gypsum wallboard manufacturing

Gypsum wallboard is manufactured in a two-step process. In the first step finely crushed and ground gypsum, calcium sulfate dihydrate ($CaSO_4 \times 2H_2O$), is heated and partially dehydrated (calcined) to calcium sulfate hemihydrate ($CaSO_4 \times 1/2H_2O$), called stucco in the industry, also popularly known as "Plaster of Paris". A unique characteristic of stucco is that when mixed with the proper amount of water, it forms a smooth plastic mass that can be molded into various shapes. When hardening is complete, the mass has been chemically restored to its rock like state – calcium sulfate dihydrate. In the second step of the manufacturing process the stucco is mixed with a number of additives. A foaming agent and an excess amount of water is also added to prepare a gypsum slurry which is extruded on a fast moving, board production line between two layers of gypsum paper. The "raw" gypsum board is then allowed to fully hydrate – calcium sulfate hemihydrate is converted back to dihydrate – before it is cut to the desired size and before it enters a heated kiln, where at elevated temperatures excess water is driven off.

The gypsum board is then packaged and stacked, ready to be shipped.

Figure 5 shows all unit processes and pollution abatement equipment included in the gate-to-gate system boundaries for gypsum board manufacturing process. The production mass-weighted average LCI data for gypsum board manufacturing are reported in Annex A, Table A3. Inbound and outbound transportation data for gypsum board manufacturing are provided in Annex A, Tables A6 and A7.

6. Life cycle impact assessment

6.1. Impact assessment indicators derived from LCA

Per Smart EPD Part A PCR Section 7.3 (5), the following impact assessment indicators describing environmental impacts derived from LCA are reported as described in Table 9.

Table 9: LCIA category indicators

Category indicator	Unit (per Declared Unit)	Source of the characterization method	Level of site specificity selected	Environmental media
Global warming potential - Total (GWP 100-total)	kg CO_2 eq.	Environmental Footprint 3.1 (IPCC 2021, AR6)	Global	Air
Global warming potential - Fossil (GWP 100-fossil)	kg CO_2 eq.	Environmental Footprint 3.1 (IPCC 2021, AR6)	Global	Air
Global warming potential - Biogenic (GWP 100-bio)	kg CO_2 eq.	Environmental Footprint 3.1 (IPCC 2021, AR6)	Global	Air
Global warming potential - Land Use and Land Use Change (GWP 100-luluc)	kg CO_2 eq.	Environmental Footprint 3.1 (IPCC 2021, AR6)	Global	Air

Category indicator	Unit (per Declared Unit)	Source of the characterization method	Level of site specificity selected	Environmental media
Acidification potential (AP)	kg SO_2 eq.	TRACI 2.2 2024	North America	Air, Water
Eutrophication potential, freshwater (EP-f)	kg P eq.	TRACI 2.2 2024	North America	Air, Water
Eutrophication potential, marine (EP-m)	kg N eq.	TRACI 2.2 2024	North America	Air, Water
Smog formation potential (SFP)	kg O_3 eq.	TRACI 2.2 2024	North America	Air
Depletion potential of the stratospheric ozone layer (ODP)	kg CFC-11 eq.	TRACI 2.2 2024/WMO:2003	Global	Air
Abiotic depletion potential, elements (ADP_e)	kg Sb eq.	CML-baseline, v4.8 2016	Global	Resource use
Abiotic depletion potential, fossil (ADP_f)	MJ, LHV	CML-baseline, v4.8 2016	Global	Resource use

6.2. Inventory indicators

Per Smart EPD Part A PCR Section 7.2.10 and 7.2.14 (5), the following mandatory inventory indicators describing resource use, waste categories and output flows are reported as described in Table 10.

Table 10: Parameters describing resource use, waste categories and output flows

Parameter	Unit (per Declared unit)
Resource Use	
RPR_E: Renewable primary resources used as energy carrier (fuel)	MJ, LHV
RPR_M: Renewable primary resources with energy content used as material	MJ, LHV
RPR_T: Total renewable primary resource use	MJ, LHV
$NRPR_E$: Non-renewable primary resources used as an energy carrier (fuel)	MJ, LHV
$NRPR_M$: Non-renewable primary resources with energy content used as material	MJ, LHV
$NRPR_T$: Total non-renewable primary resource use	MJ, LHV
SM: Secondary materials	kg
RSF: Renewable secondary fuels	MJ, LHV
NRSF: Non-renewable secondary fuels	MJ, LHV
RE: Recovered energy	MJ, LHV
FW: Consumption of freshwater	m^3
Waste Categories	
HWD: Hazardous waste disposed	kg
NHWD: Non-hazardous waste disposed	kg
HLRW: High level radioactive waste, conditioned, to final repository	kg
ILLRW: Intermediate and low level radioactive waste, conditioned, to final repository	kg

Parameter	Unit (per Declared unit)
Output Flows	
CRU: Components for re-use	kg
MR: Materials for recycling	kg
MER: Materials for energy recovery	kg
EE: Exported energy	MJ, LHV

6.3. Additional inventory indicators describing emissions and removals of carbon

As described by Smart EPD Part A PCR, Section 7.2.7 (5), the following indicators describing the uptake and emissions of CO_2 are reported as described in Table 11 below.

Table 11: Additional inventory indicators describing emissions and removals of carbon

Parameter	Unit (per Declared unit)
BCRP: Biogenic Carbon Removal from Product	kg CO_2
BCEP: Biogenic Carbon Emission from Product	kg CO_2
BCRK: Biogenic Carbon Removal from Packaging	kg CO_2
BCEK: Biogenic Carbon Emission from Packaging	kg CO_2
BCEW: Biogenic Carbon Emission from Combusion of Waste from Renewable Sources Used in Production Process	kg CO_2
CCE: Calcination Carbon Emissions	kg CO_2
CCR: Carbonation Carbon Removals	kg CO_2

Biogenic Carbon Emissions from Combustion of Waste from Renewable Sources Used in Production Process, Calcination Carbon Emissions, and Carbonation Carbon Removals are not applicable to the gypsum board product system, and as such, have not been reported. As specified in Smart EPD Part B PCR Section 7.2.3 (6), "*Carbonation uptake and calcination emissions are not applicable to the scope of this PCR. While Figure 2 refers to a "Gypsum calcining" process in module A3, this is an industry term used to describe converting calcium sulphate dihydrate to calcium sulphate hemihydrate and is not associated with traditional calcination emissions*".

6.4. LCA results

This section summarizes the life cycle impact assessment (LCIA) results including resource use and waste generated metrics based on the cradle-to-grave life cycle inventory inputs and outputs analysis. The results are calculated based on 92.9 m^2 (1 MSF) of ½" Lightweight and ⅝" Type X conventional gypsum board with a reference service life of 75 years. It should be noted that LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks (3), (4).

Table 12: EPD Results (A1 to C4) – 92.9m² of ½" Lightweight gypsum board

Impact category and inventory indicators	Unit	A1	A2	A3	A4	A5	B1-B7	C1	C2	C3	C4[19]	A1-C4 Total[20]
GWP 100-total[1]	kg CO_2 eq	-19.2	32.6	140	34.5	46.7	0	0	8.02	0	74.1	316
GWP 100-fossil[1]	kg CO_2 eq	49.9	32.6	140	34.5	46.9	0	0	8.02	0	1.60	313
GWP 100-bio[1]	kg CO_2 eq	-69.3	3.11E-04	2.72E-03	0	-0.28	0	0	0	0	72.5	2.89
GWP 100-luluc[1]	kg CO_2 eq	0.23	2.81E-04	5.70E-03	0	4.79E-02	0	0	0	0	9.84E-05	0.28
AP[2]	kg SO_2 eq	0.12	0.36	0.11	0.28	0.15	0	0	4.68E-02	0	1.35E-02	1.08
EP-f[2]	kg P eq	5.58E-03	3.51E-05	2.81E-03	2.67E-06	3.51E-03	0	0	6.23E-07	0	7.86E-06	1.19E-02
EP-m[2]	kg N eq.	3.06E-02	7.64E-02	2.23E-02	8.18E-02	3.47E-02	0	0	1.36E-02	0	3.65E-03	0.26
SFP[2]	kg O_3 eq	1.87	9.11	2.55	9.81	3.36	0	0	1.64	0	0.44	28.8
ODP[2]	kg CFC-11 eq	5.81E-07	1.71E-07	9.35E-07	6.57E-08	2.43E-07	0	0	1.54E-08	0	2.60E-08	2.04E-06
ADP_e[3]	kg Sb eq	2.71E-04	1.32E-07	9.92E-06	1.06E-07	3.48E-05	0	0	2.41E-08	0	5.59E-08	3.16E-04
ADP_f[3]	MJ, LHV	698	107	2123	10.2	614	0	0	2.32	0	20.9	3576
RPR_e	MJ, LHV	118	0.19	25.5	2.22E-03	116	0	0	5.04E-04	0	0.50	261
RPR_m[4]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
RPR_t	MJ, LHV	118	0.19	25.5	2.22E-03	116	0	0	5.04E-04	0	0.50	261
$NRPR_e$	MJ, LHV	846	107	2155	10.2	677	0	0	2.32	0	21.4	3820
$NRPR_m$[5]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
$NRPR_t$	MJ, LHV	846	107	2155	10.2	677	0	0	2.32	0	21.4	3820
SM[6]	kg	336	0	0	0	33.6	0	0	0	0	0	370
RSF[7]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
NRSF[8]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
RE[9]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
FW[10]	m^3	1.04	0	0.45	0	0.15	0	0	0	0	0	1.64
HWD[11]	kg	1.55	5.70E-03	0.17	0	1.13	0	0	0	0	1.18E-03	2.85
NHWD[12]	kg	24.0	6.63E-02	15.5	0	84.6	0	0	0	0	611	735
HLRW[13]	kg	1.48E-04	1.32E-06	7.87E-05	0	5.23E-05	0	0	0	0	4.21E-07	2.81E-04
ILLRW[14]	kg	5.21E-04	2.81E-06	2.69E-04	0	4.54E-03	0	0	0	0	1.19E-06	5.33E-03
CRU[15]	kg	-	-	-	-	-	-	-	-	-	-	-
MR[16]	kg	0	0	3.99E-02	0	3.99E-03	0	0	0	0	0	4.39E-02
MER[17]	kg	-	-	-	-	-	-	-	-	-	-	-
EE[18]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
BCRP	kg CO_2	71.0	0	0	0	8.59	0	0	0	0	0	79.6
BCEP	kg CO_2	0	0	0	0	7.10	0	0	0	0	72.5	79.6
BCRK	kg CO_2	0	0	0.50	0	4.95E-02	0	0	0	0	0	0.54
BCEK	kg CO_2	0	0	0	0	0.54	0	0	0	0	0	0.54

Table 13: EPD Results (A1 to C4) – 92.9m² of ⅝" Type X conventional gypsum board

Impact category and inventory indicators	Unit	A1	A2	A3	A4	A5	B1-B7	C1	C2	C3	C4[19]	A1-C4 Total[20]
GWP 100-total[1]	kg CO_2 eq	-13.1	52.1	216	54.3	59.0	0	0	12.6	0	74.6	455
GWP 100-fossil[1]	kg CO_2 eq	55.6	52.1	216	54.3	59.1	0	0	12.6	0	2.53	452
GWP 100-bio[1]	kg CO_2 eq	-68.9	5.65E-04	-8.37E-02	0	-0.15	0	0	0	0	72.1	2.93
GWP 100-luluc[1]	kg CO_2 eq	0.19	5.10E-04	8.61E-03	0	4.47E-02	0	0	0	0	1.55E-04	0.24
AP[2]	kg SO_2 eq	0.14	0.61	0.17	0.44	0.20	0	0	7.37E-02	0	2.12E-02	1.65
EP-f[2]	kg P eq	6.10E-03	6.33E-05	3.73E-03	4.20E-06	3.70E-03	0	0	9.82E-07	0	1.24E-05	1.36E-02
EP-m[2]	kg N eq.	3.28E-02	0.12	3.55E-02	0.13	4.61E-02	0	0	2.14E-02	0	5.75E-03	0.40
SFP[2]	kg O_3 eq	2.27	14.9	4.26	15.5	4.74	0	0	2.58	0	0.69	44.9
ODP[2]	kg CFC-11 eq	9.07E-07	3.00E-07	1.37E-06	1.03E-07	3.37E-07	0	0	2.42E-08	0	4.09E-08	3.08E-06
ADP_e[3]	kg Sb eq	9.51E-04	2.26E-07	1.60E-05	1.67E-07	1.03E-04	0	0	3.79E-08	0	8.81E-08	1.07E-03
ADP_f[3]	MJ, LHV	762	192	3321	16.1	751	0	0	3.66	0	32.9	5079
RPR_e	MJ, LHV	109	0.35	28.2	3.50E-03	116	0	0	7.94E-04	0	0.79	254
RPR_m[4]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
RPR_t	MJ, LHV	109	0.35	28.2	3.50E-03	116	0	0	7.94E-04	0	0.79	254
$NRPR_e$	MJ, LHV	907	192	3364	16.1	815	0	0	3.66	0	33.8	5332
$NRPR_m$[5]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
$NRPR_t$	MJ, LHV	907	192	3364	16.1	815	0	0	3.66	0	33.8	5332
SM[6]	kg	425	0	0	0	42.5	0	0	0	0	0	467
RSF[7]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
NRSF[8]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
RE[9]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
FW[10]	m^3	1.03	0	0.77	0	0.18	0	0	0	0	0	1.99
HWD[11]	kg	1.48	1.03E-02	0.26	0	1.13	0	0	0	0	1.86E-03	2.88
NHWD[12]	kg	31.2	0.12	19.4	0	124	0	0	0	0	963	1137
HLRW[13]	kg	1.78E-04	2.40E-06	1.15E-04	0	5.92E-05	0	0	0	0	6.64E-07	3.56E-04
ILLRW[14]	kg	6.30E-04	5.09E-06	3.76E-04	0	4.56E-03	0	0	0	0	1.87E-06	5.57E-03
CRU[15]	kg	-	-	-	-	-	-	-	-	-	-	-
MR[16]	kg	0	0	0.11	0	1.14E-02	0	0	0	0	0	0.13
MER[17]	kg	-	-	-	-	-	-	-	-	-	-	-
EE[18]	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-
BCRP	kg CO_2	70.6	0	0	0	8.55	0	0	0	0	0	79.1
BCEP	kg CO_2	0	0	0	0	7.06	0	0	0	0	72.1	79.1
BCRK	kg CO_2	0	0	0.60	0	5.97E-02	0	0	0	0	0	0.66
BCEK	kg CO_2	0	0	0	0	0.66	0	0	0	0	0	0.66

Notes to Table 12 and Table 13:

[1)] 100-year time horizon GWP factors are sourced from the IPCC 2021 Sixth Assessment Report (AR6), as adopted by the Environmental Footprint 3.1 (EF 3.1) characterization method. Biogenic carbon includes biogenic CO_2 removals and emissions associated with biobased products and packaging, such as starch, dextrose, facing & backing paper, and paper tape.

[2)] Calculated as per U.S EPA TRACI 2.2, SimaPro v 10.2.0.1 (13).

[3)] Calculated as per CML-IA Baseline v4.8, SimaPro v 10.2.0.1 (13). ADPf is also required in LEED V4.1 MR Credit2: Building Product Disclosure and Optimization – Environmental Product Declarations (16).

[4)] Calculated as per ACLCA ISO 21930 Guidance (17), 6.2 Renewable primary resources with energy content used as a material, RPR_M. N/A for gypsum boards, and indicator is not supported by secondary datasets. Reported as "-".

[5)] Calculated as per ACLCA ISO 21930 Guidance (17), 6.4 Non-renewable primary resources with energy content used as a material, RPR_M. N/A for gypsum boards, and indicator is not supported by secondary datasets. Reported as "-".

[6)] Calculated as per ACLCA ISO 21930 Guidance (17)(17), 6.5 Secondary materials, SM. This includes post-consumer gypsum, synthetic (FGD) gypsum, and mixed waste papers used in gypsum paper manufacturing.

[7)] Calculated as per ACLCA ISO 21930 Guidance (17), 6.6 Renewable secondary fuels, RSF. N/A for gypsum boards, and indicator is not supported by secondary datasets. Reported as "-".

[8)] Calculated as per ACLCA ISO 21930 Guidance (17), 6.7 Non-renewable secondary fuels, NRSF. N/A for gypsum boards, and indicator is not supported by secondary datasets. Reported as "-".

[9)] Calculated as per ACLCA ISO 21930 Guidance (17), 6.8 Recovered energy, RE. N/A for gypsum boards, and indicator is not supported by secondary datasets. Reported as "-".

[10)] Calculated as per ACLCA ISO 21930 Guidance (17), 9 Inventory indicators describing consumption of freshwater. Note the US LCI electricity dataset used in the modelling includes known errors around water usage flows, and as such, the consumption of freshwater has been calculated as an inventory metric based on primary LCI data from gypsum manufacturing facilities, paper mills, and gypsum ore extraction facilities.

[11)] Calculated as per ACLCA ISO 21930 Guidance (17), 10.1 Hazardous waste disposed. This is calculated based on primary and secondary data sources.

[12)] Calculated as per ACLCA ISO 21930 Guidance (17), 10.2 Non-hazardous waste disposed. This is calculated based on primary and secondary data sources.

[13)] Calculated as per ACLCA ISO 21930 Guidance (17), 10.3 High-level radioactive waste, conditioned, to final repository. It should be noted that the foreground system (A3 manufacturing process) does not generate any HLRW. High-level radioactive waste, e.g., when generated by electricity production, consists mostly of spent fuel from reactors." (ISO 21930:2017, clause 7.2.14).

[14)] Calculated as per ACLCA ISO 21930 Guidance (17), 10.4 Intermediate- and low-level radioactive waste, conditioned, to final repository. It should be noted that the foreground system (A3 manufacturing process) does not generate any ILLRW. Low- and intermediate-level radioactive wastes, e.g., when generated by electricity production, arise mainly from routine facility maintenance and operations (ISO 21930:2017, clause 7.2.14).

[15)] Calculated as per ACLCA ISO 21930 Guidance (17), 10.5 Components for re-use, CRU. N/A for gypsum boards, and indicator is not supported by secondary datasets. Reported as "-".

[16)] Calculated as per ACLCA ISO 21930 Guidance (17), 10.6 Materials for recycling, i.e. secondary material used in the next product system.

[17)] Calculated as per ACLCA ISO 21930 Guidance (17), 10.7 Materials for energy recovery, i.e. secondary fuels used in the next product system. N/A for gypsum boards, and indicator is not supported by secondary datasets. Reported as "-".

[18)] Calculated as per ACLCA ISO 21930 Guidance (17), 10.8 Recovered energy exported from the system. N/A for gypsum boards, and indicator is not supported by secondary datasets. Reported as "-".

[19)] Biogenic carbon release from facing and backing paper at end-of-life is the dominant contributor to the GWP impact in module C4.

[20)] The A1-C4 Total results have been reported in the LCA Report as requested by the client. The A1-C4 Total results are not reported in the EPD, as specified in ISO 21930 Section 7.1.7.1 (2).

6.4.1. Reporting of biogenic carbon

As specified in Smart EPD Part B PCR, Section 7.2.7 (6), starch, dextrose, and recycled raw materials used to produce paper are counted as biogenic carbon. Calculations for the biogenic carbon content contained in the product and packaging are presented in Table 14 below.

Table 14: Biogenic CO_2 content contained in the product and packaging – 92.9 m^2 (1 MSF) of ½" Lightweight and ⅝" Type X conventional

Inputs	Chemical formula	C-Content (%)	Biogenic CO_2 Content (kg CO_2/ MSF)	
			½" Lightweight	⅝" Type X conventional
Product				
Paper facing[1)]	$(C_6H_{10}O_5)_n$	45%	**35.21 kg CO_2/MSF** = 21.34 kg × 0.45 × (44/12)[2)]	**33.07 kg CO_2/MSF** = 20.04 kg × 0.45 × (44/12)[2)]
Paper backing[1)]	$(C_6H_{10}O_5)_n$	45%	**27.44 kg CO_2/MSF** = 16.63 kg × 0.45 × (44/12)[2)]	**30.44 kg CO_2/MSF** = 18.45 kg × 0.45 × (44/12)[2)]
Starch	$(C_6H_{10}O_5)_n$	44%	**6.52 kg CO_2/MSF** = 4.04 kg × 0.44 × (44/12)[2)]	**5.65 kg CO_2/MSF** = 3.5 kg × 0.44 × (44/12)[2)]
Dextrose[3)]	$C_6H_{12}O_6$	40%	**1.85 kg CO_2/MSF** = (0.65+0.61) kg × 0.40 × (44/12)[2)]	**1.41 kg CO_2/MSF** = (0.68+0.28) kg × 0.40 × (44/12)[2)]
Packaging				
Paper end tape[1)]	$(C_6H_{10}O_5)_n$	45%	**0.33 kg CO_2/MSF** = 0.2 kg × 0.45 × (44/12)[2)]	**0.48 kg CO_2/MSF** = 0.3 kg × 0.45 × (44/12)[2)]
Cardboard Edge Protectors[1)]	$(C_6H_{10}O_5)_n$	45%	**0.16 kg CO_2/MSF** = 0.1 kg × 0.45 × (44/12)[2)]	**0.11 kg CO_2/MSF** = 0.07 kg × 0.45 × (44/12)[2)]
Installation				
Paper joint tape[1)]	$(C_6H_{10}O_5)_n$	45%	**1.49 kg CO_2/MSF** = 0.90 kg × 0.45 × (44/12)[2)]	**1.49 kg CO_2/MSF** = 0.90 kg × 0.45 × (44/12)[2)]

Notes:

[1)] For paper making, the best fibers are those that consist of cellulose with substantial quantities of hemi-cellulose, but with all the lignin and extractives removed. Paper and board substrates can therefore be regarded as carbohydrates that contain 45% carbon by weight (18).

[2)] 44 and 12 is the molar mass of CO_2 and C (in g/mol), respectively.

[3)] It includes the amount of dextrose that is applied directly to the board (not part of BMA, Table 2), and the amount of dextrose mixed with land plaster to produce BMA (a.k.a, heat resistant accelerator, HRA). The mass-weighted average amount of dextrose in BMA resulted to 15%.

[4)] Data are rounded to an appropriate number of significant digits (2 to 3).

The calculation procedures for reporting biogenic carbon (GWP-100 bio, BCRP, BCEP, BCRK, BCEP) follow the guidance provided in EPD International Part A PCR Annex 2 (19), which states the following:

"*The amount of biogenic carbon is an inherent material property, which sometimes is not included, or correctly accounted for, in secondary datasets available in LCA software. Therefore, the amount of biogenic carbon in the product or the packaging – which is*

needed to correctly calculate the GWP-biogenic results and account for the content declaration – may have to be checked and added manually."

The biogenic carbon calculated manually based on first principles is added or subtracted (depending on whether the biogenic carbon is entering or leaving the product system) to the GWP-100 bio results generated in SimaPro using Environmental Footprint 3.1 (IPCC AR6) methodology. The net effect of biogenic carbon stored in the product/packaging is zero ("0") over the course of the product life cycle.

7. Interpretation

Interpretation is the phase of LCA in which the findings from the inventory analysis and the impact assessment are brought together and significant issues are identified and considered in the context of the study goal and scope (3). In addition, the study's completeness, consistency of all applied information, and sensitivity to key assumptions or parameters as they relate to the goal and scope of the study are evaluated. Lastly, the interpretation phase ends by drawing conclusions, stating the study's limitations, and making recommendations (4).

7.1. Identification of significant issues

ISO 14044 recommends several possible methods to identify significant issues in an LCA study. Based on established LCA practices, the following analytical techniques were applied for the interpretation phase of this LCA study (4):

- Contribution analysis, in which the contribution of information modules and processes to the cradle-to-gate LCA results are examined.
- Dominance analysis, in which significant contributions are examined.

Figure 6 and Figure 7 present the impact assessment and energy indicator results for 92.9 m^2 (1 MSF) of ½" Lightweight and ⅝" Type X conventional gypsum boards by information module on a percent contribution basis.

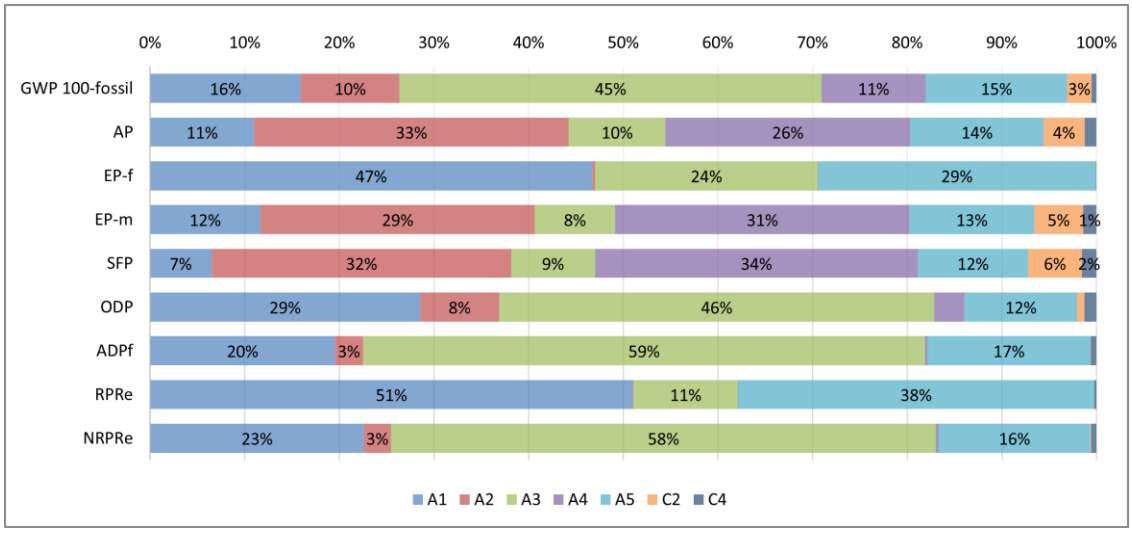


Figure 6: Contribution Analysis by Information Module for ½" Lightweight

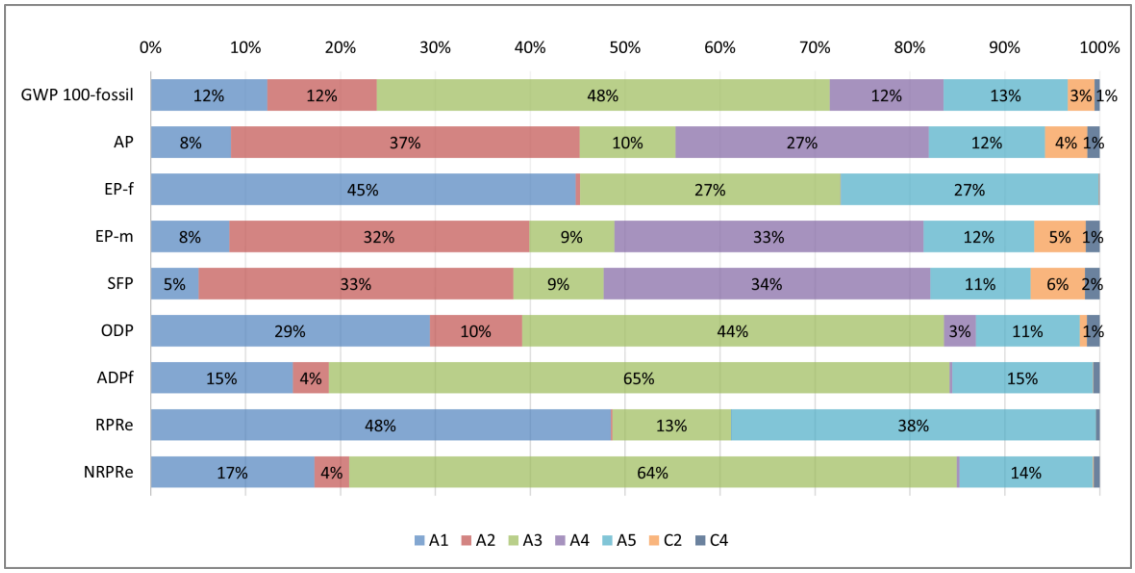


Figure 7: Contribution Analysis by Information Module for ⅝" Type X

Across both declared products, *Module A3 Manufacturing*, and *Module A1, Extraction and Upstream Production* typically contribute the largest share of the LCIA and energy indicator results. *Module A5, Installation* also contributes significantly to the overall environmental impact across all major impact categories. *Module A2, Transportation,* and *Module A4, Transportation to Construction Site* are significant contributors to the global warming, acidification, marine eutrophication, and smog formation potential environmental indicators. *Module C2 End of Life Transportation* and *Module C4 Waste Disposal* are generally minor contributors to the potential environmental impact of gypsum board over the product's life cycle, and each module typically contributes less than 5% to the total environmental impact across all major impact categories.

Over 96% of the total primary energy is derived from non-renewable primary energy resources. On-site energy use at the plant (natural gas and purchased electricity) and the facing and backing paper input are the major contributing sources to total primary energy use.

Furthermore, Figure 8 and Figure 9 illustrate the results of the process dominance analysis for 92.9 m^2 (1 MSF) of ½" Lightweight and ⅝" Type X conventional gypsum board products. The process dominance analysis shows that natural gas usage is typically the primary process contributing to the potential environmental impact of both gypsum board products across many of the major environmental impact categories. Transportation to manufacturing facility, and transport to site are also significant contributors to the potential environmental impact. Gypsum & formulation materials (A1) is generally a minor contributor to the potential environmental impacts across all major impact categories.

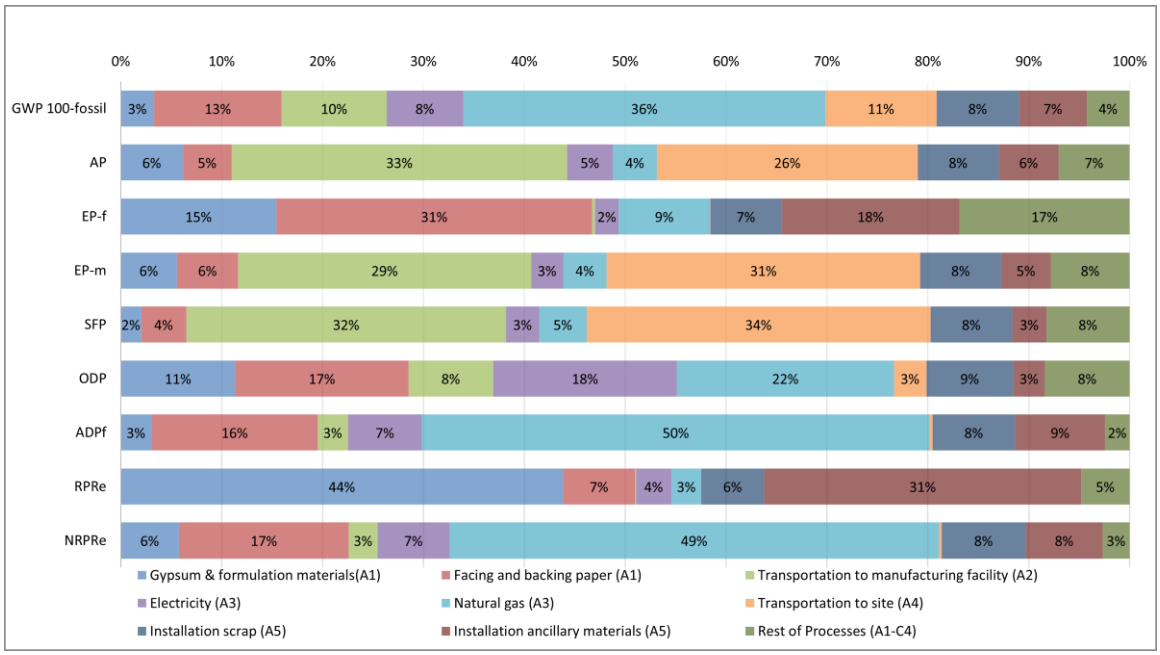


Figure 8: Process Dominance Analysis – 92.9 m² (1 MSF) of ½" Lightweight gypsum board – percent basis

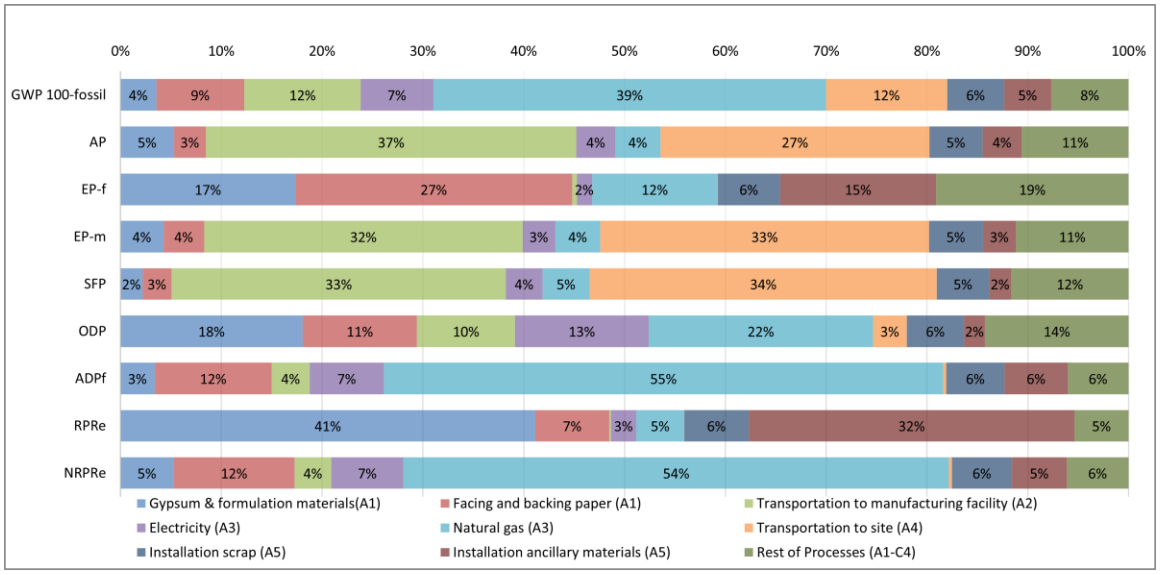


Figure 9: Process Dominance Analysis – 92.9 m² (1 MSF) of ⅝" Type X conventional gypsum board – percent basis

7.2. Completeness, consistency, and sensitivity check

Evaluating the study's completeness, consistency and sensitivity helps to establish and enhance confidence in, and the reliability of, the results of the LCA study, including the significant issues identified in the first element of the interpretation (4).

The objective of the *completeness check* is to ensure that all relevant information and data needed for the interpretation are available and complete (4). Both ½" Lightweight and ⅝" Type X conventional gypsum board systems were checked for data completeness. All input and output data were found to be complete and no gaps were identified.

The objective of the *consistency check* is to determine whether the assumptions, methods, models, and data are consistent with the goal and scope of the study (4). Through a rigorous process, consistency was ensured between the two gypsum board product systems in terms of calculation rules, methods, models, and data quality, including data source, time-related coverage, technology, and geographical coverage (see Section 5, and Annex B). Table 8 summarizes the data quality assessment conducted in the framework of this LCA study.

To assess how factors such as uncertainties in data, and assumptions would affect the reliability of the results and conclusions, a *sensitivity check* was conducted. The *sensitivity check* includes the results of the *sensitivity analysis* and *uncertainty analysis* (4).

The sensitivity analysis procedure is a comparison of the LCA results obtained using certain given assumptions, methods, or data, with the LCA results obtained using altered assumptions, methods, or data (4). ISO 14044 Clause B.3.3 states: "*Sensitivity can be expressed as the percentage of change or as the absolute deviation of the results. On this basis, significant changes in the results (e.g., larger than 10%) can be identified*" (4).

As documented in Section 5.1 and Annex B, the weighted average electricity grid based on the balancing authority of each participating facility. Scenario analysis was conducted to illustrate the consequences of replacing the weighted average electricity profile with the US electricity grid for ½" Lightweight and ⅝" Type X conventional gypsum board.

The scenario analysis results are presented in detail in Table 15 and Table 16 below for both ½" Lightweight and ⅝" Type X conventional gypsum board product systems, specifically for the Production Stage (A1-A3) results. The positive (+) or negative (-) signs of deviation (in %) depend on the mathematical signs (+/-) of both the value of base case and the deviation of the LCIA and energy indicators. For example, the influence of this scenario to GWP 100-fossil of the ⅝" Type X Conventional compared to the base case is positive (+0.5%) and indicates a 0.5% higher GWP compared to the base case. The scenario analysis shows that the US national weighted average LCI profile for electricity grid (for foreground processes only) were deemed not significant sensitivity scenario. In general, the sensitivity case resulted in less than 1% change across major environmental indicators, except for RPRE, EP-f, and ODP for both ½" Lightweight and ⅝" Type X conventional gypsum board systems. The results indicate the use of the national average electricity profile in lieu of the calculated weighted average electricity profile does not significantly affect the results of the study for both ½" lightweight and ⅝" Type X conventional gypsum board.

Table 15: Sensitivity Analysis Scenario 1: Production Stage Results for 92.9 m^2 (1 MSF) of ½" Lightweight – Substitution of Mass-weighted Average Electricity Profile with US Average

Base Case: Mass-*weighted Average Electricity Profile*

Sensitivity Case: *US Average Electricity Profile*

Indicator	Unit	Base Case	Sensitivity Case	Absolute Deviation	Percent Deviation
GWP 100-fossil	kg CO_2 eq.	222	221	-1.60	-0.7%
ODP	kg CFC-11 eq.	1.69E-06	1.65E-06	-4.06E-08	-2.4%
SFP	kg O_3 eq.	13.5	13.6	0.06	0.4%
AP	kg SO_2 eq.	0.59	0.59	-1.27E-03	-0.2%
EP-f	kg P eq.	8.43E-03	8.16E-03	-2.66E-04	-3.2%
EP-m	kg N eq.	0.13	0.13	7.60E-04	0.6%
ADPf	MJ	2928	2924	-3.48	-0.1%
RPRe	MJ, LHV	144	136	-8.1	-5.6%
NRPRe	MJ, LHV	3108	3101	-7.3	-0.2%

Table 16: Sensitivity Analysis Scenario 1: Production Stage Results for 92.9 m^2 (1 MSF) of ⅝" Type X conventional – Substitution of Mass-weighted Average Electricity Profile with US Average

Base Case: Mass-*weighted Average Electricity Profile*

Sensitivity Case: *US Average Electricity Profile*

Indicator	Unit	Base Case	Sensitivity Case	Absolute Deviation	Percent Deviation
GWP 100-fossil	kg CO_2 eq.	324	324	0.87	0.3%
ODP	kg CFC-11 eq.	2.58E-06	2.67E-06	8.83E-08	3.4%
SFP	kg O_3 eq.	21.4	21.3	-9.91E-02	-0.5%
AP	kg SO_2 eq.	0.91	0.92	8.25E-03	0.9%
EP-f	kg P eq.	9.90E-03	9.72E-03	-1.83E-04	-1.8%
EP-m	kg N eq.	0.19	0.19	1.02E-03	0.5%
ADPf	MJ	4275	4293	18.0	0.4%
RPRe	MJ, LHV	138	132	-5.6	-4.0%
NRPRe	MJ, LHV	4464	4479	15.37	0.3%

Sensitivity analysis was also conducted for *on-site natural gas consumption* at the gypsum board manufacturing facilities, as this is the primary contributor to the potential environmental impacts for both product systems.

The coefficient of variation (COV) for the on-site natural gas consumption factor per 92.9 m^2 (1 MSF) of gypsum board products has been calculated to be approximately 11% for ½" Lightweight and 17% for ⅝" Type X gypsum board. The COV is the ratio of the standard

deviation to the arithmetic mean, and represents a normalized measure of the dispersion of the sample data. Sensitivity analysis was conducted to illustrate the consequences of a 17% change in natural gas consumption on the LCIA and energy indicator results for ⅝" Type X conventional gypsum board. The results of this scenario are documented below in Table 16 The sensitivity analysis indicate that a 16% change in plant natural gas consumption would result in around 9% change in the production stage GWP 100-fossil for ⅝" Type X conventional gypsum board.

For best identification of significant sensitivity parameters (SP), sensitivity is calculated as the ratio (R_{sp}) of the percentage change in LCA indicator results over the percentage change in the parameter value. The sensitivity analysis shows that the natural gas consumption factor is deemed a significant sensitivity parameter, with a R_{SP} of 0.54. Similar findings are applicable for the ½" Lightweight gypsum board product system as well.

Table 17: Sensitivity Analysis Scenario 2: Production Stage Results for 92.9 m² (1 MSF) of ⅝" Type X – Variation in Natural Gas Usage

Base Case: *Mass-weighted Average Natural Gas Usage at Plant*

Sensitivity Case: *Natural Gas Usage Increased by 16% (COV)*

Indicator	Unit	Base Case	Sensitivity Case	Absolute Deviation	Percent Deviation
GWP 100-fossil	kg CO_2 eq.	324	352	28.2	8.7%
ODP	kg CFC-11 eq.	2.58E-06	2.69E-06	1.10E-07	4.3%
SFP	kg O_3 eq.	21.4	21.8	0.34	1.6%
AP	kg SO_2 eq.	0.91	0.93	1.18E-02	1.3%
EP-f	kg P eq.	9.90E-03	1.02E-02	2.70E-04	2.7%
EP-m	kg N eq.	0.19	0.20	2.81E-03	1.5%
ADPf	MJ	4275	4726	451	10.5%
RPRe	MJ, LHV	138	139	1.72	1.3%
NRPRe	MJ, LHV	4464	4919	455	10.2%

A Monte Carlo uncertainty analysis was also conducted to assess the combined uncertainty effect of the data variability on the LCIA and energy indicator results – refer to Annex C for the results of the Monte Carlo uncertainty analysis.

Based on the industry sample data, the minimum and maximum range data was calculated per each input/output flow from the primary data for natural gypsum extraction, gypsum paper production, and gypsum board manufacturing. This data is used in the Monte Carlo uncertainty analysis. The uncertainty analysis assesses the combined uncertainty effect of the inventory data (both foreground and background. It should be noted that the US EPA TRACI 2.2 methodology has not specified any uncertainty information of the characterization factors per impact category.

As a statistical method to process data uncertainty, Monte Carlo analysis is used to establish uncertainty range, which expresses the variance between the upper and lower confidence limit [97.5%, 2.5%], in the calculated LCA results. *Based on 1,000 runs, such information provides a quantitative indication of the range of results that are likely for the gypsum manufacturer's specific products covered by the industry average EPD for two selected gypsum board products.*

7.3. Conclusions, limitations, and recommendations

Based on the goal and scope of this LCA, life cycle inventory, impact assessment, and interpretation phases, the following conclusions can be reached:

- The use of *FGD synthetic gypsum* and *post-consumer paper (Module A1)* is environmentally beneficial for the gypsum board industry as it reduces the dependency on primary material resources (natural gypsum ore and virgin paper stock).
- *Module A2 Transportation is dominated by both the ocean freighter transportation of imported FGD synthetic gypsum and natural gypsum, as well as long-haul truck transportation of gypsum ore and facing & backing paper.*
- *Module A3 Manufacturing* generally contributes the largest share of the LCIA category indicator results.
- Over 96% of the total primary energy used in the production stage (A1-A3) is derived from *non-renewable primary energy resources* for both ½" Lightweight and ⅝" Type X gypsum board product systems.
- On-site natural gas usage (module A3) accounts for 36% to 39% of the total life-cycle (A1 to C4) global warming potential (GWP 100- fossil).
- *A5, Installation* is typically a minor contributor to the overall potential environmental impact of gypsum board, except for the RPRe and EP-f environmental indicators, of which the *installation ancillary material usage* contributes 32% and 15% of the total life cycle impact for RPRe and EP-f respectively for ⅝" Type X conventional gypsum board.
- *Module C2 End of Life Transportation* and *Module C4 Waste Disposal* are generally minor contributors to the potential environmental impact of gypsum board over the product's life cycle, and each module typically contributes less than 5% to the total environmental impact across all major impact categories.

For best interpretation and appropriate use of the LCA results for EPD, it is important to state the inherent ***limitations*** and assumptions of the LCA technique. "*LCA addresses potential environmental impacts and does not predict absolute or precise environmental impacts due to (a) the relative expression of potential environmental impacts to a reference unit, (b) the integration of environmental data over space and time, (c) the inherent uncertainty in modeling of environmental impacts, and (d) the fact that some possible environmental impacts are clearly future impacts*" (4).

The GA gypsum board manufacturing facilities produce other co-products besides selected gypsum boards and as such allocation based on the mass of gypsum board products was necessary. This methodological approach is expected to be "conservative" for ⅝" Type X conventional gypsum board products.

Based on the EPD results "on-site" energy conservation efforts at GB manufacturing facilities are strongly **recommended**. The EPD study results indicate that "on-site" energy use is the single largest contributor to the cradle-to-grave EPD results. More specifically, efforts to reduce natural gas use offer the most immediate opportunity to improve the environmental performance of GB plants and products.

8. Additional Environmental Information

8.1. GWP 100 indicator results per IPCC 2021 (AR6) and IPCC 2013 (AR5)

The previous iteration of the Gypsum Association's industry average LCA for gypsum board has used the IPCC 2013 AR5 methodology. IPCC 2021 AR6 is the successor of the IPCC 2013 AR5 method. Table 18 shows the cradle-to-gate GWP-100 total indicator results per IPCC 2013 AR5 and IPCC 2021 AR6 for 92.9 m^2 (1 MSF) of ½" Lightweight and ⅝" Type X conventional gypsum board.

Table 18: Production Stage (A1-A3) GWP-100 total indicator results per IPCC 2021 AR6 and IPCC 2013 AR5 for 92.9 m^2 (1 MSF) of ½" Lightweight and ⅝" Type X conventional

Impact Assessment Method	Unit	½" Lightweight	⅝" Type X conventional
IPCC 2021 AR6	kg CO_2 eq.	224.69	325.96
IPCC 2013 AR5	kg CO_2 eq.	224.82	326.13

Note: The values above illustrate the GWP-total values calculated by the IPCC AR6 Methodology in SimaPro, without considering the manual calculations for removals and emissions associated with biogenic material. The values above are provided for illustrative purposes to show the variation in GWP due to methodological changes, and do not align with the GWP-total values reported in Section 6.4.

8.2. Health Protection Manufacture

The OSHA standards are applicable and followed.

- U.S. Department of Labor, Occupational Safety & Health Administration (OSHA), 29 CFR, PART 1910 Occupational Safety and Health Standards.
https://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=STANDARDS&p_toc_level=1&p_keyvalue=1910

No additional health protection measures extending beyond mandatory occupational safety measures for commercial operations are required.

8.3. Environmental Protection Manuacture and Equipment

The GA member manufacturing facilities comply with the regional North American environmental protection requirements, monitor and report the emissions to air during the manufacturing process as per the following:

- EPCRA Section 313 Toxic Release Inventory reporting (U.S) https://www.epa.gov/toxics-release-inventory-tri-program

- The Canadian National Pollutant Release Inventory (NPRI) reporting http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1,

Pollution abatement equipment typically used in the gypsum board manufacturing facilities consist of high and low temperature baghouses, bin vent, cartridge filter, precipitator and water sprinkler for dust control.

8.4. H_2S Formation

Hydrogen sulfide (H_2S) formation in Municipal Solid Waste (MSW) and Construction & Demolition (C&D) landfills requires a sulfate source, carbon source, anaerobic conditions, moisture, pH, and temperature. Gypsum panels are a significant contributor to H_2S formation.

Problems and Solutions:

Issues in Landfill Gas (LFG) Projects: High H_2S concentrations in LFG can cause engine wear and corrosion, leading to more frequent maintenance. Combustion of H_2S-rich LFG emits sulfur dioxide (SO_2), a regulated pollutant with strict emission limits in the U.S.

Prevention Measures: Diverting gypsum panels from landfills can reduce H_2S formation. Some landfills ban drywall disposal, except in small amounts. Recycling markets for gypsum drywall (e.g., agricultural soil amendments, new drywall production) help reduce landfill deposits.

9. Declaration type and product average declaration

The type of EPDs based on this project report are defined as:

-A "Cradle-to-grave" EPD for ½" Lightweight and ⅝" Type X conventional gypsum boards covering the Production, Use, and End-of-Life stages (A1-C4) and is intended for use in Business-to-Business and Business-to-Consumer communications.

The Gypsum Association's EPDs fall under the description:

- An average product EPD, as an average from from several GA manufacturers' facilities

10. Declaration comparability limitation statement

The following statement from Smart EPD Part A PCR indicates the EPD comparability limitations and intent to avoid any market distortions or misinterpretations of EPDs based on the Smart EPD Part B PCR for Gypsum Panel Products (5), (6):

A manufacturer shall not make claims based on an industry-average EPD which leads the market to believe the industry-average is representative of manufacturer-specific or product-specific results.

Environmental declarations from different programs (ISO 14025) may not be comparable. Comparison of the environmental performance of products using EPD information shall be based on the product's use and impacts at the building or construction works level, and therefore EPDs may not be used for comparability purposes when not considering the whole building life cycle. EPD comparability is only possible when all stages of a life cycle have been considered. However, variations and deviations are possible. Example of variations: Different LCA software and background LCI datasets may lead to differences in results upstream or downstream of the life cycle stages declared.

11. EPD explanatory material

For any explanatory material in regard to GA EPDs based on this LCA project report, please contact the program operator:

Smart EPD

info@smartepd.com
www.smartepd.com

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