Athena Sustainable Materials Institute

www.athenasmi.org

An Industry Average Cradle-to-Gate Life Cycle Assessment of 1/2" Regular and 5/8" Type X Glass-mat Gypsum Board for the USA and Canadian Markets

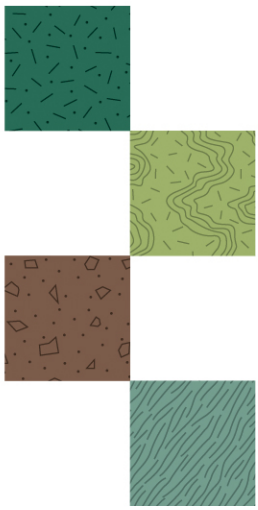
EPD Project Report

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.

Commissioner: Gypsum Association

EPD Program Operator: ASTM International

April 2021

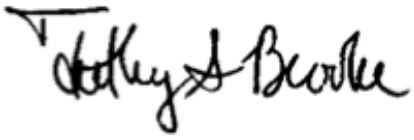


General Summary

This LCA background report presents industry average results for 1/2" Regular and 5/8" Type X glass-mat gypsum boards as produced by Gypsum Association members in the US and Canada. The LCA has been completed to support a Type III Environmental Product Declaration (EPD) for glass-mat gypsum boards conforming to ASTM C1177/C1177M- 17 *Standard Specification for Glass Mat Gypsum Substrate for Use as Sheathing* [1]. Specifically, this industry average LCA background report (named the "*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], NSF International product category rules (PCR) for preparing an environmental product declaration for gypsum panel products [5] and ASTM International's EPD program operator rules [6]. This underlying LCA report for EPD development purposes was commissioned by the Gypsum Association and its members and is verified by ASTM International to conform to the requirements of ISO 14040 [3], 14044 [4],14025 [7], and 21930 [2].

General Summary	
Owner of the EPD	
GYPSUM ASSOCIATION™	**Gypsum Association (GA)** 962 Wayne Avenue, Suite 620 Silver Spring, MD 20910 Link (URL): www.gypsum.org, info@gypsum.org The GA is a not-for-profit trade association founded in 1930. Its mission is to promote the use of gypsum while advancing the development growth, and general welfare of the gypsum industry in the United States (U.S.) and Canada on behalf of its member companies. GA members include all the active gypsum panel product manufacturers in the U.S. and Canada. GA member companies provided both LCI and meta-data for the reference year 2019. GA members, with the inclusion of their Canadian holdings and affiliates, produce and ship over 95% of the glass-mat gypsum boards consumed in the USA and Canada. The owner of the declaration is liable for the underlying information and evidence.
GA Member Companies Corporate Locations	
AMERICAN GYPSUM	American Gypsum Company LLC 3811 Turtle Creek Blvd., Suite 1200 Dallas, TX 75219, USA Member Link (URL): http://www.americangypsum.com/
CertainTeed SAINT-GOBAIN Gypsum	CertainTeed Gypsum, Inc. CertainTeed Gypsum Canada, Inc. 20 Moores Road Malvern, PA 19355, USA Member Link (URL): http://www.certainteed.com/gypsum *In the course of completing this EPD project Continental Building Products (CBP) was acquired by CertainTeed. CBP also provided operational data to support this project).*

General Summary	
	Georgia-Pacific Gypsum LLC 133 Peachtree Street NE Atlanta, GA 30303, USA Member Link (URL): http://www.buildgp.com/Georgia-Pacific-Gypsum
	National Gypsum Company 2001 Rexford Road Charlotte, North Carolina 28211, USA Member Link (URL): http://nationalgypsum.com/
	PABCO® Gypsum 10600 White Rock Road, Suite 100 Rancho Cordova, CA 95670, USA Member Link (URL): http://www.pabcogypsum.com/
 	United States Gypsum Company 550 West Adams Street Chicago, IL 60661-3676, USA Member Link (URL): https://www.usg.com/content/usgcom/en.html Canadian Gypsum Company (CGC) Inc. 350 Burnhamthorpe Road West 5th Floor Mississauga, ON, L5B 3J1, Canada Member Link (URL): https://www.usg.com/content/usgcom/en_CA_east.html
Product Group and Name	Glass-mat gypsum board
Product Description	Glass-mat gypsum boards are designed to be used as exterior substrate or sheathing for weather barriers. The substrates consist of a non-combustible water-resistant gypsum core, surfaced with glass mat partially or completely embedded in the core.
Product Category Rules (PCR)	NSF International, Product Category Rule for Environmental Product Declarations, PCR for Gypsum Panel Products, April 2020 [5].
Certification Period	05.01.2021 - 05.01.2026
Declared Unit	92.9 m^2 (1,000 square feet) of glass-mat gypsum board with a nominal finished thickness of ½" and $^5/_8$".
ASTM Declaration Number	EPD 206

EPD and Project Report Information	
Program Operator	ASTM International
Declaration Holder	Gypsum Association (GA)
Declaration Type A "cradle-to-gate" EPD for glass-mat gypsum boards manufactured by GA members. Activity stages or information modules covered include production with the product ready for shipment at the manufacturing plant (modules A1 to A3). The declaration is intended for use in Business-to-Business (B-to-B) communication.	
Applicable Countries United States and Canada	
Product Applicability Glass-mat gypsum boards are typically used as exterior building envelope sheathing providing weather barriers, mold and fire resistance for new construction or renovation work.	
Content of the Declaration This declaration follows *Section 9*; *Content of an EPD*, NSF International, Product Category Rule for Environmental Product Declarations: PCR for Gypsum Panel Products, April 2020 [5].	
This EPD was independently verified by ASTM in accordance with ISO 14025 and the reference PCR: **Internal** **External** X	 Tim Brooke, ASTM International
The Project Report *Note that this Project Report is not part of the public communication (ISO 21930, 10.1).*	An Industry Average Cradle-to-Gate Life Cycle Assessment of 1/2" Regular and 5/8" Type X Glass-mat Gypsum Board for the USA and Canadian Markets, April 2021.
Prepared by Athena Sustainable Materials Institute	Lindita Bushi, PhD, Mr. Jamie Meil and Mr. Grant Finlayson 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 by in accordance with ISO 14025, ISO 14040/44, and the reference PCR:	Thomas P. Gloria, Ph. D. Industrial Ecology Consultants 35 Bracebridge Rd. Newton, MA
PCR Information	
Program Operator	ASTM International
Reference PCR	NSF International, Product Category Rule for Environmental Product Declarations: PCR for Gypsum Panel Products [5].
Date of Issue	April 2020
PCR review was conducted by:	Thomas P. Gloria, PhD (Chair), Industrial Ecology Consultants, t.gloria@industrial-ecology.com Mr. Jack Geibig, EcoForm Mr. Bill Stough, Sustainable Research Group

Terms and Definitions

ISO 14040/Amd1:2020 and ISO 14044:2006/Amd1:2017/Amd2:2020 [3], [4] – Clause 3 Terms and Definition.

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 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.

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 uncertainty in the results.

ISO 14021:2016 [9]- Clause 7.8 Recycled content

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 [7] - 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 [2] - Clause 3 Terms and definitions

Average data: Data based on a fully representative sample for a construction product or 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.

Declared unit: Quantity of a construction product for use as a reference unit in an EPD based on LCA for the expression of environmental information in information modules.
Note 1 to entry: The declared unit is used where the function and the reference scenario for the whole life cycle, on the construction works level, cannot be stated.

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 to entry: For consideration of environmental impacts and environmental aspects, the life cycle comprises all stages, from raw material acquisition or generation from natural resources to end-of-life.

Based on NSF PCR:2020 [5] - 3 Terms and definitions

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

Glass-mat gypsum board: the generic name for a family of sheet products consisting of a non-combustible core primarily of gypsum with a nonwoven facing (ASTM C11 – 18b).

Gypsum panel products: The general name for a family of sheet products consisting essentially of gypsum.

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

ADP_f	Abiotic depletion potential for fossil resources
ASCC	Alaska Systems Coordinating Council, NERC
AP	Acidification potential
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
EE	Recovered energy exported from the product system
EP	Eutrophication potential
EPD	Environmental product declaration
FFD	Fossil fuel depletion
FGD	Flue gas desulfurization, synthetic gypsum
FRCC	Florida Reliability Coordinating Council, NERC
FW	Consumption of fresh water
GA	Gypsum Association
GWP 100	Global warming potential, 100 years' time horizon
LHV	Lower heating value or net caloric value
HICC	Hawaiian Islands Coordinating Council, NERC
HLRW	High-level radioactive waste, conditioned, to final repository
HWD	Hazardous waste disposed
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
LEED	Leadership in Energy and Environmental Design
MC	Moisture content
MER	Materials for energy recovery
MJ	Mega joule
MR	Materials for recycling
MRO	Midwest Reliability Organization, US part only, NERC
MSF	Thousand square feet
N	Nitrogen
NAICS	North American Industry Classification System

NERC	The North American Electric Reliability Corporation
NHWD	Non-hazardous waste disposed
NPCC	Northeast Power Coordinating Council, US part only, NERC
NPRI	Canadian National Pollutant Release Inventory
$NRPR_M$	Non-Renewable primary energy carrier used as material
$NRPR_E$	Non-renewable primary energy carrier used as energy
NRSF	Non-renewable secondary fuel
NSF	National Center for Sustainability Standards
O_3	Ozone
ODP	Ozone depletion potential
O+M	Building Operations and Maintenance, LEED
OSHA	Occupational Safety & Health Administration
PCR	Product category rules
PM	Particulate Matter
RE	Recovered energy,
RFC	Reliability First Corporation, NERC
RPR_M	Renewable primary energy carrier used as material
RPR_E	Renewable primary energy carrier used as energy
RSF	Renewable secondary fuel
SERC	Southeastern Electric Reliability Council, NERC (a.k.a, SERC Reliability Corporation)
SFP	Smog formation potential
SM	Secondary material
SO_2	Sulfur dioxide
SPP	Southwest Power Pool, NERC
tkm	Tonne-kilometre
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
TRE	Texas Regional Entity, NERC
TRI	United States Toxics Release Inventory (TRI) Program
UN CPC	United Nations Central Product Classification
US EPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
WECC	Western Electricity Coordinating Council, US part only, NERC.

1 Introduction

The US Green Building Council's *Leadership in Energy and Environmental Design* (LEED) v4 and v4.1 green rating system, 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.

This life *cycle assessment* (LCA) project report supports an *environmental product declaration* (EPD) for the production stage of glass-mat gypsum boards ready for shipment at the plant gate in the USA and Canada and as such has a business-to-business (B2B) 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 [7]. 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.

This study demonstrates the Gypsum Association (GA) and its members' commitment to transparently sharing the environmental footprint of glass-mat gypsum boards and in support of generating an EPD for users of glass-mat gypsum boards both in the USA and Canada.

In support of this study, primary LCI data were collected from a representative sample of 11 GA members producing glass-mat gypsum boards. This LCA study considered the scale of operations including a mix of small, medium and large facilities, their geographical location by census region and their source of gypsum – adjacent quarry, mine, imported natural gypsum ore and their use of flue gas desulfurized (FGD) synthetic gypsum (both domestic and imported). The study also drew on recent primary data for natural or crude gypsum ore extraction (six quarries and one underground mining site). Lastly, a major glass matting US manufacturer provided confidential LCIA and LCI indicator results for a typical glass mat product used in the manufacturing of glass-mat gypsum boards for production year 2017 to support this project.

[1] *Building Design and Construction (BD+C); Interior Design and Construction (ID+C); Neighborhood Development (ND)*.
LEED v4, MR Credit 2, EPDs- Option 1 applies to BD+C rating system (New Construction, Core & Shell, Schools, Retail, Data Centers, Warehouses & Distribution Centers, Hospitality, and Healthcare: 1 point); ID+C rating system (Commercial Interiors, Retail, and Hospitality: 1 point), ND rating system (new land developments, land redevelopments, residential, mixed use, commercial, and industrial: 1 point); and Homes rating system (Homes, Multifamily Lowrise, Multifamily Midrise: 1 point) [17].
LEED v4.1, MR Credit 2, EPDs- Option 1 (similar to v4): 1 point [18].

2 Study Goals

2.1 Goals of the Study

This is a sector-driven initiative by the Gypsum Association and its members to conduct an LCA to support the development of a Type III EPD according to ISO 14025 [7], the NSF PCR [5], and ISO 21930 [2] for glass-mat gypsum boards, as manufactured and distributed in North America (United States and Canada) by GA members.

2.2 Intended Applications and Audience

This LCA report is intended to support the development of an EPD for use in Business-to-Business (B-to-B) communication. The intended audience for the EPD include GA and its member companies, their suppliers, architectural, engineering, and 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

This Project Report (underlying LCA report for EPD) is 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 [5].

Per ISO 21930, 10.1 [2], this Project Report shall be made available to the verifier with the requirements on confidentiality stated in ISO 14025 [7]. This Project Report was independently verified by Thomas Gloria PhD, Industrial Ecology Consultants, in accordance with ISO 14025 [7], ISO 14040/44 [3], [4], and the NSF PCR requirements [5].

3 Product Identification

3.1 Product Description

Glass-mat gypsum boards UNSPSC Code 30161500, as defined in ASTM C1177 are designed to be used as an exterior substrate or sheathing for weather barriers [1]. The substrates consist of a non-combustible water-resistant gypsum core, surfaced with a glass mat partially or completely embedded in the core [1]. Typically, glass-mat gypsum boards are 4' wide and 8' length boards (4'×8') produced with a square edge but they may be available in other lengths and can vary in thickness depending on the application.
The focus of this industry average LCA study is on two glass-mat gypsum boards used for *exterior sheathing* applications (walls and soffits).

- $^{1}/_{2}$" (12.7 mm) glass-mat gypsum board (Regular core, ASTM C1177), and
- $^{5}/_{8}$" (15.9 mm) Type X glass-mat gypsum board (Type X core, ASTM C1177).

The weighted average density of 1/2" Regular glass-mat gypsum board (MC 0%) was determined to be 10.0 kg/m^2, with a minimum and maximum density value of 8.2 and 12.7 kg/m^2 (MC 0%), respectively. Similarly, the weighted average density of $^5/_8$" Type X glass-mat gypsum board (MC 0%) was 13.4 kg/m^2, with a minimum and maximum density value of 10.9 and 15.8 kg/m^2, respectively.

This study does not cover glass-mat gypsum panels used in *interior wall and ceiling applications* (ASTM C1658). In addition, this study does not cover *glass-mat gypsum roof board* (ASTM C1177), *glass-mat gypsum panel abuse & impact resistant* (ASTM C1629), and *glass-mat gypsum tile backer (ASTM C1178)*. Glass-mat gypsum boards are also proprietary products and while they all employ glass matting and a water-resistant gypsum core the panel composition varies across manufacturers. Figure 1 below provides a visual of a glass-mat gypsum board.

Figure 1 Generic glass-mat gypsum board

3.2 Product Standard

Applicable product standards for glass-mat gypsum boards (UNSPSC Code 30161500) include:

- ASTM C1177/ C1177M–17 *Standard Specification for Glass Mat Gypsum Substrate for Use as Sheathing*
- ASTM C11–18b *Terminology Relating to Gypsum and Related Building Materials and Systems*
- ASTM C22 / C22M–00(15) *Standard Specification for Gypsum*
- ASTM C473–17 *Standard Test Methods for Physical Testing of Gypsum Panel Products*
- ASTM C1264– 19*Specification for Sampling, Inspection, Rejection, Certification, Packaging, Marking, Shipping, Handling, and Storage of Gypsum Panel Products*
- ASTM E119–18ce1 *Test Methods for Fire Tests of Building Construction and Materials*
- ASTM E2921–16a *Standard practice for minimum criteria for comparing whole building LCAs for use with building codes, standards, and rating systems*.

3.3 Material Content

Table 1 below presents the weighted average composition by input material for 92.9 m^2 (one thousand square feet, 1 MSF) of glass-mat gypsum boards as derived from the GA member facilities LCI data collection for the reference year 2019. The final weight of each glass-mat gypsum board includes chemically bounded water.

Table 1 Weighted average material content for 92.9 m² (1 MSF) of glass-mat gypsum boards by thickness

Inputs	1/2" Regular glass-mat gypsum board	5/8" Type X glass-mat gypsum board	Units
Natural gypsum ore	1,458.4	1,890.8	lbs
FGD synthetic gypsum	355.4	509.9	lbs
Post-consumer gypsum[1)]	3.24	2.06	lbs
Glass matting	113.4	116.9	lbs
Starch	1.59	1.06	lbs
Continuous filament glass fiber	2.44	3.61	lbs
Dispersant	4.00	5.90	lbs
Retarder	0.16	0.45	lbs
Potassium Sulfate	1.43	1.48	lbs
Boric Acid	0.076	0.096	lbs
Land Plaster	0.60	0.33	lbs
Foaming agent (soap)	0.26	0.33	lbs
Ball mill accelerator (BMA)	3.97	2.83	lbs
Edge Paste	2.68	3.66	lbs
Fly ash	1.42	1.11	lbs
Other Chemicals[2)]	2.47	6.78	lbs
Silicone products	7.18	7.16	lbs
Wax	7.26	11.43	lbs
Other (MgO, Portland cement)	0.14	0.21	lbs
Water	1,355.2	1,788.0	lbs
Final weight, with MC%/ MSF	*2,078.9*	*2,784.4*	*lbs*
Final moisture content	1.40%	1.66%	%
Final weight, with 0% MC/ MSF	*2,048.7*	*2,735.9*	*lbs*

Notes:
[1)] Post-consumer gypsum includes on-site construction off-cuts and recovered gypsum material collected from demolition sites.
[2)] It consists of biocide, sodium omadine, sodium trimetaphosphate, barium metaborate monohydrate (Busan) and emulsion solids. LCI data have been rolled up to protect confidential/proprietary information.

4 Scope of the Study

4.1 Declared Unit

The *declared unit* is defined as the quantity of a construction product for use as a reference unit in an EPD based on LCA for the expression of environmental information in information modules [2], [5].

Per NSF PCR, Section 7.1.4 [5], the declared unit for this LCA study is defined as 92.9 m² (1 MSF) of glass-mat gypsum boards with a nominal finished thickness of ½" and $^5/_8$" (see Table 2). A declared unit is defined for EPDs covering the cradle-to-gate *Production stage* which consists

of three alpha-numeric modules: A1 Extraction and upstream production; A2 Transport to factory; and A3 Manufacturing [2].

Table 2 Declared unit definition

Item	1/2" Regular glass-mat gypsum board	5/8" Type X glass-mat gypsum board	Units
Declared unit	92.9	92.9	m^2
Mass	943	1263	kg
Thickness	12.7	15.9	mm
Final MC	1.4	1.7	%
Core type	Regular	Type X	n/a

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

4.2 System Boundary

For this Project Report, the boundary is “cradle-to-gate” or the *Production stage*, which includes extraction of raw materials (cradle) through the manufacture of glass-mat gypsum boards ready for shipment (gate). Downstream activity stages - *Construction*, *Use*, *End-of-life*, and *Optional supplementary information beyond the system boundary* - are excluded from the system boundary (see Figure 2). Figures 3 presents the *Production stage* system boundary for the declared glass-mat gypsum board product system. Per ISO 21930, 7.1.7.2.1 [2], the system boundary with nature includes those technical processes that provide the material and energy inputs into the system and the subsequent manufacturing and transport processes up to the factory gate, as well as the processing of any waste arising from those processes. Per NSF PCR, Section 7.1.7.2 [5], 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 (flue gas desulfurization (FGD) synthetic gypsum, de-watering at coal-power plants), but not including those processes that are part of the waste processing in the previous product system;

— A1, cradle-to-gate production of glass matting, and formulation materials (a.k.a, formulation additives);

— A1, cradle-to-gate generation of electricity used for extraction and processing of natural gypsum ore, and processing of FGD synthetic gypsum to make it usable as material input (de-watering process);

— 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.

A2, Transport to factory

This information module includes weighted average transportation data of all input materials (raw gypsum, synthetic gypsum, glass matting, formulation materials, secondary, ancillary, and shipping & packaging materials) from extraction site or source to glass mat panel manufacturing site, and including empty backhauls and transportation to interim distribution centers or terminals.

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 glass-mat gypsum boards and co-products (see Figure 3);

— A3, waste management from manufacturing packaging and manufacturing wastage including weighted average transportation data up to the recycler or disposal.

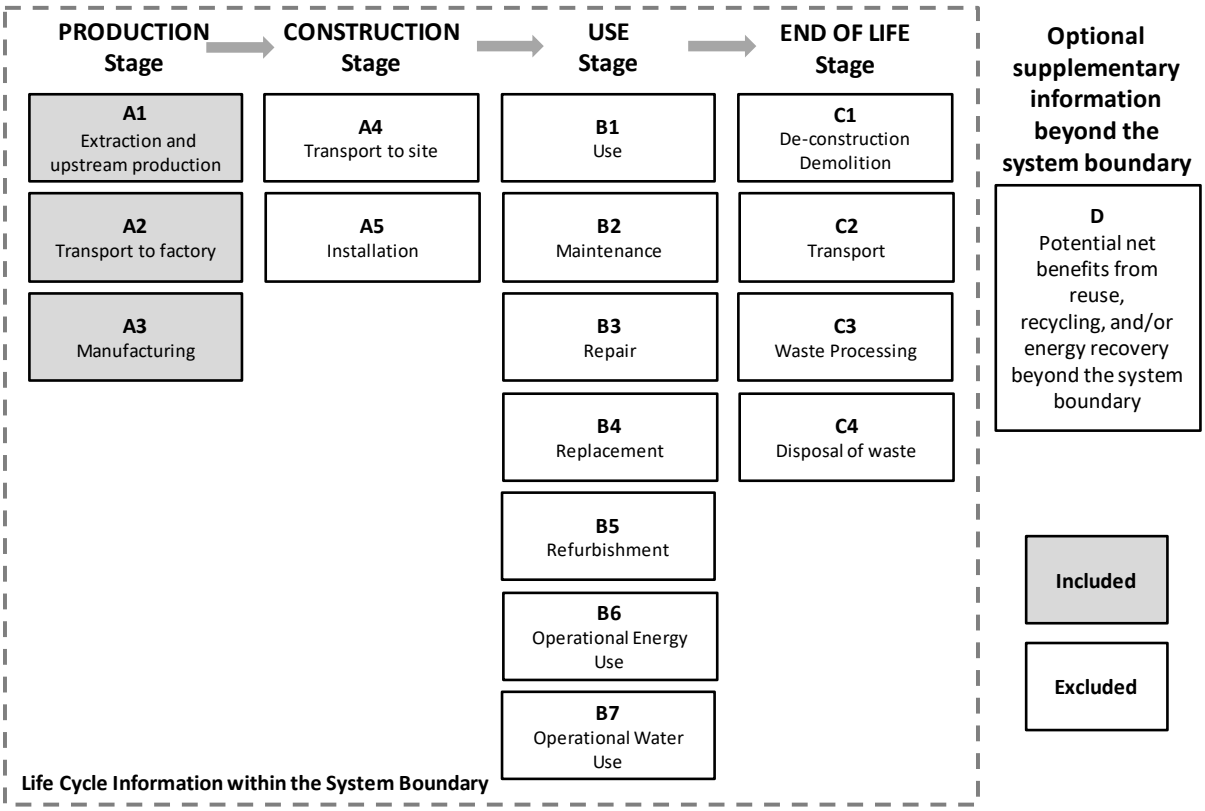


Figure 2 Common four life cycle stages and their information modules for construction products and the optional supplementary module [2]

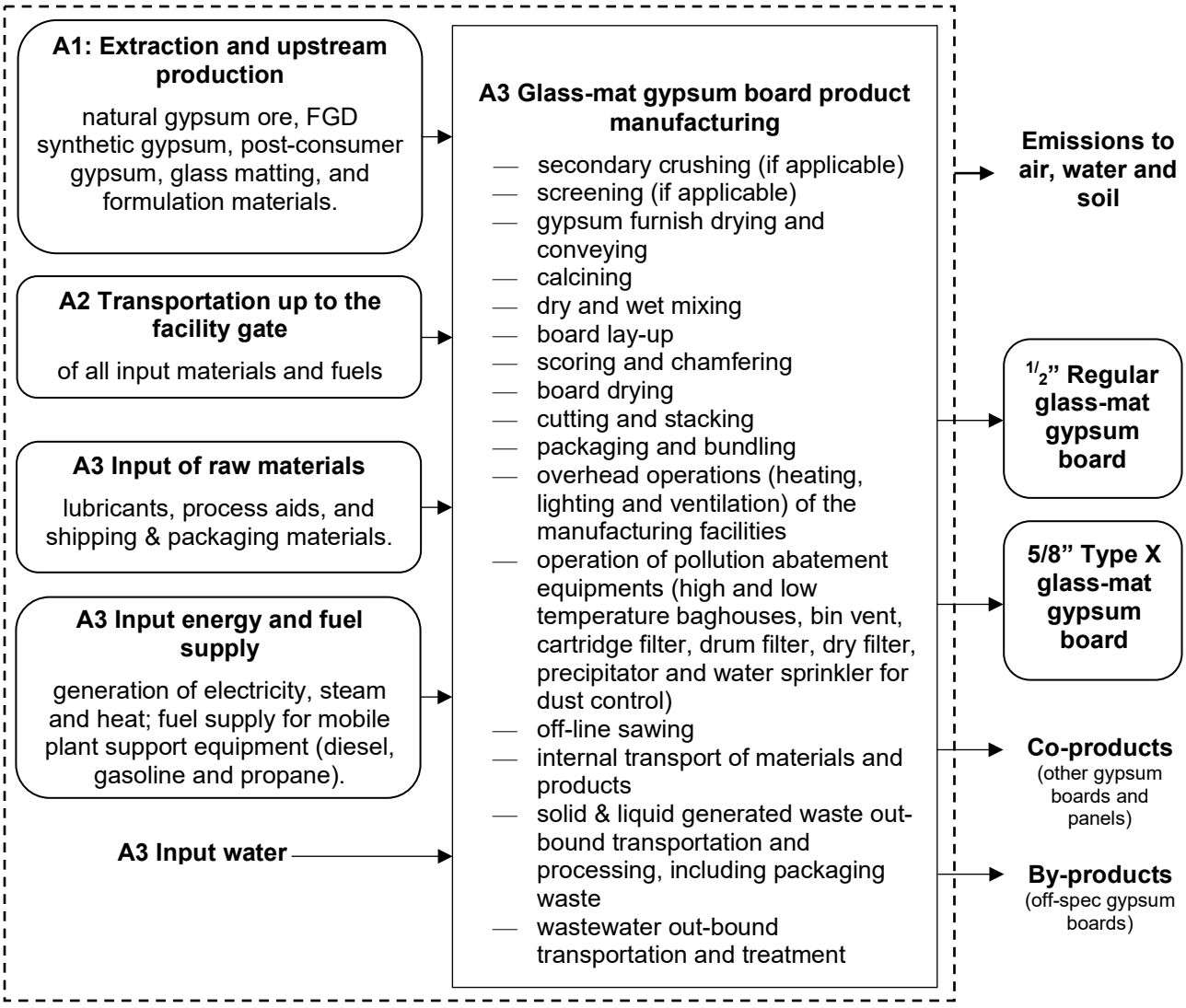


Figure 3: Production Stage (Modules A1 to A3) System Boundary

4.3 Cut-off Criteria

The cut-off criteria as per NSF PCR, Section 7.1.6 [5] and ISO 21930, 7.1.8 [2] were followed for this Project Report. Per ISO 21930, 7.1.8 [2], all input/output data required 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 were identified in the framework of this EPD. Any plant specific data gaps for the reference year 2019 e.g., hydraulic fluids, lubricants, oils, packaging materials or transportation were filled in with plant generic data from previous years or industry average data. Material Safety Data Sheet (MSDSs) were confidentially provided by GA plants per each chemical class e.g., dispersant, retarder chemicals, etc. Any data gaps in the MSDS are filled in with two (proxy) generic LCI datasets, as appropriate (*conservative* assumptions): *Chemical, organic {GLO}| production | Cut-off, U*; *Chemical, inorganic {GLO}| production | Cut-off, U- see Annex C, Table C1 for details.*

Per NSF PCR, Section 7.1.6 [5], the Production Stage *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 within the factory site or at another location.

4.4 LCA Software

The LCA model was developed using SimaPro v.9.1.1.1 2021 (https://simapro.com/), an LCA software used by industry and academics in more than 80 countries for 25 years [14]. SimaPro LCA software contains recognized databases (e.g., U.S. LCI database and ecoinvent v3.6 database, Allocation, Cut-off by classification) that provide LCI datasets for upstream, core, and downstream material and processes. It also contains the U.S. EPA TRACI 2.1 LCIA methodology and the Cumulative Energy Demand, LHV version 1.0 which are used for this LCA study for EPD.

5 Life Cycle Inventory

5.1 Data Collection, Representativeness, Sources, and Calculations

Data collection was based on an initial survey of all GA member facility operations. GA members operate 51 facilities in the USA and Canada producing various gypsum board and panel products. Some facilities are 100% dedicated to the production of glass-mat gypsum boards while others may produce glass-mat gypsum boards as well as other gypsum panel products. In total 11 facilities operated by the seven (7) GA company members (American Gypsum Company LLC, CertainTeed Gypsum, Inc., CertainTeed Gypsum Canada, Inc., Continental Building Products, Georgia-Pacific Gypsum LLC, National Gypsum Company, PABCO® Gypsum, United States Gypsum Company and CGC Inc.) completed LCI data collection questionnaires representing 35% of all GA member facilities producing glass-mat gypsum boards.

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. A representative sample of glass-mat gypsum board plants within its membership was identified based on technical attributes, production scale and geographic location to arrive at a *representative* sample of glass-mat gypsum board manufacturing plants.
Described below is the well-defined plant selection platform for inclusion in the industry-average study sample.

- 11 glass-mat gypsum board manufacturing plants were selected to adequately represent:
  - GA's membership production volume (including having at least *one plant* from *each GA member company* participate in the study);
  - the scale of plant operations including *a mix of small, medium and large* operations;
  - the geographical representation of the participating facilities included facilities from three discrete regions (East, Midwest and Western US).
- 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 Canada or Spain depending on plant location).

This project draws on foreground gate-to-gate LCI data collected for natural gypsum ore extraction (six quarries and one underground mining site) for the reference year 2017. In addition, a major glass matting US manufacturer provided confidential LCIA and LCI indicator results for a typical glass mat product used in the manufacturing of glass-mat gypsum boards for production year 2017 (see Table B1, Annex B).

LCI data collection was based on a customized LCI survey for the GA glass-mat gypsum board manufacturing facilities. The LCI survey covered the following *primary data* for each facility for the 2019 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 applicable);

- Solid waste;
- Wastewater and other liquid waste; and
- Waste outputs and their respective outbound transportation distances and modes.

Source of data is specified as (see Annex A, Table A1):
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*;

Annex A, Table A1 summarizes the weighted average LCI data for the glass-mat gypsum board product system by thickness. Annex A, Table A2 and A3 present the transportation modes and weighted average distance (in ton-mile or t-km) for all inputs and outputs for each product thickness, respectively. Transportation activities are included consistently in the respective life cycle module (A1, A2, A3).

Per NSF PCR, Section 5.3 [5] and ISO 21930, 5.3 [2], all facility specific LCI data were weighted based on total annual production to calculate the weighted average LCI profile for glass-mat gypsum boards (per MSF)- see Annex A, Table A5. Table A6 summarizes the product packaging waste data at the installation site (NSF PCR, Section 7.1.7.3.2 [5]. All LCI data (including meta-data) were verified and benchmarked with 2013 plant specific and/or GA industry average LCI data for each product system by the Athena Institute. Note that the [minimum; maximum] range data are also calculated for each LCI flow (but not reported due to confidentiality reasons) to facilitate Monte Carlo uncertainty analysis (see Annex D).

This LCA study draws on appropriate LCI datasets provided by (see Annexes A, B and C):

- Gypsum Association and its members on glass-mat gypsum board manufacturing data (2019) and natural gypsum ore extraction (2017)- see Annex A;
- A major glass matting US manufacturer on a typical glass mat product used in the manufacturing of glass-mat gypsum boards for production year 2017 (see Annex B);
- North American and global LCI databases such as the U.S. National Renewable Energy Laboratory LCI database, September 2015 (http://www.nrel.gov/lci/), and ecoinvent 3.6, allocation, cut-off database, December 2019 (http://www.ecoinvent.org/). Both are included in the LCA software SimaPro v.9.1.1.1 2020 (see Annex C for details).

Data calculation procedures follow ISO 14044 [4], and NSF PCR for Gypsum Panel Products [5]. The same calculation procedures are applied throughout this LCA study for EPD. Per ISO 21930, 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.
Per NSF PCR, Section 7.1.10 [5], SI units are used for the LCA data and results. Other units commonly used in the market are also included in addition to the required SI units (see Annex A, Tables A1 to A4).

5.2 Data Quality Requirements and Assessments

Per NSF PCR, Section 7.1.9 [5], and ISO 21930, 7.1.9 [2], appropriate activity and LCI primary and secondary data shall be used to model glass-mat gypsum board product systems. 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 collected data and the data quality assessment regarding the NSF PCR requirements [5] and ISO 14044 [4] is provided in Annex C, Tables C1 to C3. Data quality is assessed based on its representativeness (technology coverage, geographic coverage, time coverage). completeness, consistency, reproducibility, transparency and uncertainty (see Table 3).

Table 3 Data Quality Requirements and Assessments

Data Quality Requirements	Description
Technology Coverage	Data represents the prevailing technology in use in U.S. and Canada. Whenever available, for all upstream and core material and processes, North American typical or average industry LCI datasets were utilized (see Annex C, Tables C1 to C3). *Technological representativeness is characterized as "high".*
Geographic Coverage	The geographic region considered is U.S. and Canada. The geographic coverage of all LCI databases and datasets is given in Annex C, Tables C1 to C3. *Geographical representativeness is characterized as "high".*
Time Coverage	Activity data are representative as of 2017-2019 (see Annex A, Tables A1 to A3). - Glass-mat gypsum board manufacturing process- primary data collected from 11 facilities: reference year 2019 (12 months); - In-bound/ out-bound transportation data- primary data collected from 11 facilities: reference year 2019 (12 months); - Natural gypsum ore – primary data collected from six quarries and one gypsum ore underground mine: reference year 2017 (12 months); - Glass mat manufacturing- cradle-to-gate LCIA and LCI indicator results per ISO 21930:2017 provided by a major glass matting US manufacturer to support this project: reference year 2017 (12 months); - Generic data: the most appropriate LCI datasets were used as found in the US LCI Database, ecoinvent v.3.6 database, December 2019. *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 the glass-mat gypsum board products of interest. The relevant background materials and processes were taken from the US LCI Database, ecoinvent v 3.6 LCI database, and modeled in SimaPro v9.1.1.1, 2021. The completeness of the cradle-to-gate process chain in terms of process steps is rigorously assessed for both glass-mat gypsum boards and documented in Section 4.2.

Data Quality Requirements	Description
Consistency	To ensure consistency, the LCI modeling of the production weighted input and output LCI data for the glass-mat gypsum board product of interest used the same LCI modeling structure across the selected GA member facilities, which consisted of input raw, secondary, glass matting, 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.
Reproducibility	Internal reproducibility is possible since the data and the models are stored and available in *GA Athena Glass-mat gypsum boards LCI database* developed in SimaPro, 2021. A high level of transparency is provided throughout the report as the 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 C. 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, B and C.
Transparency	Activity and LCI datasets are transparently disclosed in the project report, including data sources (see Annexes A, B and C).
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 D).

5.3 Allocation Rules

Per NSF PCR, Section 7.2.3 and 7.2.6 [5], *allocation, if required, shall follow the requirements and guidance of ISO 14044, Section 4.3.4 and shall be based on the mass of gypsum panel products produced*. *Allocation related to transport shall be based on the mass of the transported product*.

Per ISO 21930, 7.2.4, *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 glass-mat gypsum board manufacturing facilities typically produce other co-products besides selected products of interest and as such allocation based on the mass of products was necessary. Per ISO 21930, 3 [2], c*o-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 glass-mat gypsum board products of interest were used to model and calculate the required input raw materials (both primary and secondary) and water input (see Table 1). As specified in the NSF PCR, Section 7.2.3 to 7.2.6 [5], *"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. LCI modeling accounts for the plant specific fabrication yields in accordance with ISO 14044, 4.3.4.2, "*Some outputs may be partly co-products and partly waste. In such cases, it is necessary to identify the ratio between co-products and waste since the inputs and outputs shall be allocated to the co-products part only*".

Per ISO 21930, 3 [2], 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), see Figure 3, and Annex A, Table A1.

Per NSF PCR 7.1.7.2.5 and 7.2.3 [5], flue gas desulfurized synthetic gypsum is considered a recovered "waste" material and is used burden free; other than those burdens necessary to use it as an input in the manufacture of glass-mat gypsum boards. 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 glass-mat gypsum board products [10], [11]. For FGD synthetic gypsum to be a saleable product for use in glass-mat gypsum board manufacturing it needs to undergo de-watering process to reduce the moisture content to around 10% [11], [12], [13], and transport to the glass-mat gypsum board manufacturing facility. As a result, the dewatering of sludge by vacuum filtration and transport of FGD synthetic gypsum is included within the Production stage system boundary [12], [13]. It should be mentioned that saleable FGD synthetic gypsum has the same molecular composition

as raw gypsum [11]. Typically, FGD synthetic gypsum undergoes additional secondary drying at the glass-mat gypsum board plant; this drying is included in the A3 Manufacturing information module. In addition, per NSF PCR, Section 7.2.3 to 7.2.6 [5], allocation related to transport is based on the mass of transported inputs and outputs.

5.4 Glass-mat gypsum board Manufacturing

Glass-mat gypsum board 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 to 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 glass matting. The “raw” glass-mat 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 glass-mat gypsum board is then packaged and stacked, ready to be shipped.

Figure 3 shows all unit processes and pollution abatement equipment included in the gate-to-gate system boundaries for glass-mat gypsum board manufacturing process. The production weighted average LCI data for glass-mat gypsum board manufacturing are reported in Annex A, Table A1. Inbound and outbound transportation data for glass-mat gypsum board manufacturing are provided in Annex A, Tables A2 to A3.

Purchased electricity and natural gas were reported to be the primary manufacturing energy inputs (A3). While the electricity is used at all production stages most of the natural gas is used during the drying of gypsum, calcining or stucco production and drying the final glass-mat gypsum board products. Diesel is used at plant for on-site equipment (not transportation). Gasoline and propane are typically used to operate the on-site mobile equipment (e.g., forklifts, small engine vehicles) within and around the facility. Gate-to-gate emissions to air were measured and reported at the stack after the utilization of pollution abatement equipment. Total suspended solids (TSS) and lead were the two emissions to water reported by the surveyed facilities. Lead and mercury were the two emissions to land reported by the reporting facilities.

6 Life Cycle Impact Assessment

6.1 Impact assessment indicators describing main environmental impacts derived from LCA

Per NSF PCR, Section 7.3 [5], the following impact assessment indicators are reported as described in Table 4.

Table 4 LCIA category indicators

Impact category	Category indicator	Unit (per Declared Unit)	Source of the characterization method	Level of site specificity selected	Environ-mental media
Climate change	Global warming potential (GWP 100)[1)]	kg CO_2 – equiv.	TRACI 2.1, July 2012 /with IPCC 2013, AR5[1)]	Global	Air
Ozone depletion	Depletion potential of the stratospheric	kg CFC-11 equiv.	TRACI 2.1, July 2012/WMO:2003	Global	Air
Acidification	Acidification potential (AP)	kg SO_2 equiv.	TRACI 2.1, July 2012	North America	Air, Water
Eutrophication	Eutrophication potential (EP)	kg N equiv.	TRACI 2.1, July 2012	North America	Air, Water
Smog	Smog formation potential (SFP)	kg O_3 equiv.	TRACI 2.1, July 2012	North America	Air
Abiotic depletion potential (ADP), fossil	ADP surplus	MJ, surplus	TRACI 2.1, July 2012	Global	Resource use

Note:
[1)] 100-year time horizon GWP factors (a.k.a, GWP 100a) are provided by the IPCC 2013 Fifth Assessment Report (AR5). GWP 100 indicator results *exclude* biogenic CO_2 removal and emissions associated with biobased products such as starch and dextrose (see Table 8 for details). GWP 100a indicator results, IPCC 2007 Fourth Assessment Report (AR4) are presented in Section 8.

6.2 Inventory indicators describing resource use, waste categories and output flows

Per NSF PCR, Section 7.2.10, 7.2.13, 7.2.14 [5], the following mandatory resource use, waste categories and output flows are reported as described in Table 5.

Table 5 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
$NRPR_E$: 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
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	kg
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 LCA results for EPD

This section summarizes the production stage life cycle impact assessment (LCIA) results including resource use and waste generated metrics based on the cradle-to-gate life cycle inventory inputs and outputs analysis. The results are calculated based on 92.9 m^2 (1 MSF) of $^1/_2$" and $^5/_8$" glass-mat gypsum boards. (Tables 6 and 7). *It is 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 6 Production Stage (A1-A3), EPD Results – 92.9 m^2 (1 MSF) of $^1/_2$" Regular glass-mat gypsum products

Impact category and inventory indicators[1)]	Unit	A1, Extraction and upstream production	A2, Transport to factory	A3, Manufacturing	Total
Global warming potential, GWP 100[2)], AR5	kg CO_2 eq	207.0	25.5	204.9	**437.4**
Ozone depletion potential, ODP[2)]	kg CFC-11 eq	0.0	0.0	0.0	**7.2E-05**
Smog formation potential, SFP[2)]	kg O_3 eq	12.6	10.9	6.4	**29.9**
Acidification potential, AP[2)]	kg SO_2 eq	0.8	0.5	0.3	**1.6**
Eutrophication potential, EP[2)]	kg N eq	0.7	0.0	0.3	**0.95**
ADP surplus, TRACI[3)]	MJ surplus	407.9	52.0	449.7	**910**
Renewable primary resources used as an energy carrier (fuel), RPR_E	MJ LHV	97.6	0.2	61.7	**160**
Renewable primary resources with energy content used as material, RPR_M[4)]	MJ LHV	0.0	0.0	0.0	**0**
Non-renewable primary resources used as an energy carrier (fuel), $NRPR_E$	MJ LHV	3,336	347.9	3,122	**6,806**
Non-renewable primary resources with energy content used as material, $NRPR_M$[5)]	MJ LHV	0.0	0	0.0	**0**
Secondary materials, SM[6)]	kg	162.5	0	0.0	**163**
Renewable secondary fuels, RSF[7)]	MJ LHV	0	0	0	**0**
Non-renewable secondary fuels, NRSF[8)]	MJ LHV	0	0	0	**0**
Recovered energy, RE[9)]	MJ LHV	0	0	0	**0**
Consumption of freshwater, FW[10)]	m^3	1.3	0	0.8	**2.1**
Hazardous waste disposed, HWD[11)]	kg	0.024	0	0.013	**0.037**
Non-hazardous waste disposed, NHWD[12)]	kg	8.3	0	11.1	**19.4**
High-level radioactive waste, conditioned, to final repository, HLRW[13)]	m^3	2.0E-08	1.7E-10	1.2E-07	**1.4E-07**
Intermediate- and low-level radioactive waste, conditioned, to final repository, ILLRW[14)]	m^3	1.8E-06	1.1E-06	1.8E-06	**4.7E-06**
Components for re-use, CRU[15)]	kg	0	0	0	**0**
Materials for recycling, MR[16)]	kg	0	0	26.1	**26.1**
Materials for energy recovery, MER[17)]	kg	0	0	0.0	**0**
Recovered energy exported from the product system, EE[18)]	MJ LHV	0	0	0.0	**0**

Table 7 Production Stage (A1-A3), EPD Results – 92.9 m² (1 MSF) of 5/8" Type X glass-mat gypsum boards

Impact category and inventory indicators[1)]	Unit	A1, Extraction and upstream production	A2, Transport to factory	A3, Manufacturing	Total
Global warming potential, GWP 100[2)], AR5	kg CO_2 eq	220.4	33.0	250.5	**503.9**
Ozone depletion potential, ODP[2)]	kg CFC-11 eq	0.0	0.0	0.0	**8.3E-05**
Smog formation potential, SFP[2)]	kg O_3 eq	13.9	14.4	7.4	**35.7**
Acidification potential, AP[2)]	kg SO_2 eq	0.9	0.7	0.4	**2.0**
Eutrophication potential, EP[2)]	kg N eq	0.7	0.0	0.3	**1.05**
ADP surplus, TRACI[3)]	MJ LHV	456.1	67.0	548.4	**1,072**
Renewable primary resources used as an energy carrier (fuel), RPR_E	MJ LHV	99.1	0.3	79.8	**179**
Renewable primary resources with energy content used as material, RPR_M[4)]	MJ LHV	0.0	0.0	0.0	**0**
Non-renewable primary resources used as an energy carrier (fuel), $NRPR_E$	MJ LHV	3,693	447.7	3,817	**7,958**
Non-renewable primary resources with energy content used as material, $NRPR_M$[5)]	MJ LHV	0.0	0	0.0	**0**
Secondary materials, SM[6)]	kg	232.3	0	0.0	**232**
Renewable secondary fuels, RSF[7)]	MJ LHV	0	0	0	**0**
Non-renewable secondary fuels, NRSF[8)]	MJ LHV	0	0	0	**0**
Recovered energy, RE[9)]	MJ LHV	0	0	0	**0**
Consumption of freshwater, FW[10)]	m^3	1.3	0	1.0	**2.3**
Hazardous waste disposed, HWD[11)]	kg	0.030	0	0.018	**0.048**
Non-hazardous waste disposed, NHWD[12)]	kg	8.6	0	14.0	**22.5**
High-level radioactive waste, conditioned, to final repository, HLRW[13)]	m^3	2.4E-08	2.4E-10	1.4E-07	**1.7E-07**
Intermediate- and low-level radioactive waste, conditioned, to final repository, ILLRW[14)]	m^3	2.6E-06	1.5E-06	2.3E-06	**6.4E-06**
Components for re-use, CRU[15)]	kg	0	0	0	**0**
Materials for recycling, MR[16)]	kg	0	0	41.3	**41.3**
Materials for energy recovery, MER[17)]	kg	0	0	0.0	**0**
Recovered energy exported from the product system, EE[18)]	MJ LHV	0	0	0.0	**0**

Notes to Tables 6 and 7:

[1)] Note that data may not add up to totals due to rounding. Data are rounded to an appropriate number of significant digits (2 to 4).

[2)] Calculated as per U.S EPA TRACI v2.1, with IPCC 2013 (AR 5), SimaPro v 9.1.1.1 [14].
GWP 100, excludes biogenic CO_2 removals and emissions associated with biobased products such as starch and dextrose (see Table 8 for details); 100-year time horizon GWP factors are provided by the IPCC 2013 Fifth Assessment Report (AR5), TRACI v2.1 with AR5, v1.05 [14].

[3)] ADP surplus, TRACI v2.1 (a.k.a Fossil fuel depletion, FFD) is required in LEED V4.1 MR Credit: Building Product Disclosure and Optimization – Environmental Product Declarations [18].

[4)] Calculated as per ACLCA ISO 21930 Guidance [15], 6.2 *Renewable primary resources with energy content used as a material, RPR_M.* Not applicable for the glass-mat gypsum boards (NA).

[5)] Calculated as per ACLCA ISO 21930 Guidance [15], 6.4 *Non-renewable primary resources with energy content used as a material, $NRPR_M$*- N/A.
[6)] Calculated as per ACLCA ISO 21930 Guidance [15], 6.5 Secondary materials, SM; it includes post-consumer gypsum and synthetic gypsum (FGD) used in manufacturing.
[7)] Calculated as per ACLCA ISO 21930 Guidance [15], 6.6 *Renewable secondary fuels, RSF*- N/A.
[8)] Calculated as per ACLCA ISO 21930 Guidance [15], 6.7 *Non-renewable secondary fuels, NRSF*- N/A.
[9)] Calculated as per ACLCA ISO 21930 Guidance [15], 6.8 *Recovered energy, RE*- N/A.
[10)] Calculated as per ACLCA ISO 21930 Guidance [15], 9 *Inventory indicators describing consumption of freshwater*. It's calculated from 2017 and 2019 industry average primary data for consumption of freshwater based solely on the foreground system (raw gypsum extraction, glass mat, and glass-mat gypsum boards manufacturing processes).
[11)] Calculated as per ACLCA ISO 21930 Guidance [15], 10.1 *Hazardous waste disposed*. It's calculated from 2017 and 2019 industry average primary data for hazardous waste disposed based solely on the foreground system (raw gypsum extraction, glass mat, and glass-mat gypsum boards manufacturing processes).
[12)] Calculated as per ACLCA ISO 21930 Guidance [15], 10.2 *Non-hazardous waste disposed*. It's calculated from 2017 and 2019 industry average primary data for non-hazardous waste disposed based solely on the foreground system (raw gypsum extraction, glass mat, and glass-mat gypsum boards manufacturing processes).
[13)] Calculated as per ACLCA ISO 21930 Guidance [15], 10.3 *High-level radioactive waste, conditioned, to final repository*. It should be noted that glass-mat gypsum board foreground system (raw gypsum extraction and glass-mat gypsum board manufacturing processes) 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 [15], 10.4 *Intermediate- and low-level radioactive waste, conditioned, to final repository*. It should be noted that glass-mat gypsum board foreground system (raw gypsum extraction and glass-mat gypsum board manufacturing processes) 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 [15], 10.5 *Components for re-use*- N/A.
[16)] Calculated as per ACLCA ISO 21930 Guidance [15], 10.6 *Materials for recycling*, i.e. secondary material used in the next product system.
[17)] Calculated as per ACLCA ISO 21930 Guidance [15], 10.7 *Materials for energy recovery*, i.e. secondary fuels used in the next product system- N/A.
[18)] Calculated as per ACLCA ISO 21930 Guidance [15], 10.8 *Recovered energy exported from the system*- N/A.

Per NSF PCR, 7.2.7 [5], for glass-mat gypsum board products, starch and dextrose are counted as biogenic carbon. Table 8 shows the cradle-to-gate biogenic CO_2 removals associated with bio-based products used in the glass-mat gypsum board system.

Table 8 Production Stage (A1-A3), Biogenic CO_2 removals – 92.9 m^2 (1 MSF) of 1/2" Regular and 5/8" Type X glass-mat gypsum boards

Inputs	Chemical formula	C-Content (in %)	Biogenic CO_2 removals (in kg CO_2/ MSF)	
			½" Regular glass-mat gypsum board	5/8" Type X glass-mat gypsum board
Starch	$(C_6H_{10}O_5)_n$	44%	**- 2.6** = -1.59 kg × 0.44 × (44/12)	**- 1.7** = -1.06 kg × 0.44 × (44/12)
Dextrose	$C_6H_{12}O_6$	40%	**- 0.87** = -0.60 kg × 0.40 × (44/12)	**- 0.62** = -0.42 kg × 0.40 × (44/12)

Notes:
[1)] 44 and 12 is the molar mass of CO_2 and C (in g/mol), respectively.
[2)] It includes the amount of dextrose mixed with landplaster to produce BMA (a.k.a, heat resistant accelerator, HRA). The weighted average amount of dextrose in BMA resulted to 15%.
[3)] Data are rounded to an appropriate number of significant digits (2 to 3).

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 the 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 EPD results are examined; and
- *Dominance Analysis*, in which *significant* contributions are examined.

Figures 6 and 7 present the impact assessment and energy indicator results for 92.9 m^2 (1 MSF) of $^1/_2$" Regular and $^5/_8$" Type X glass-mat gypsum boards, by *information module*, percent contribution basis, respectively.

The cradle-to-gate manufacture of 92.9 m^2 of 12.7 mm (1 MSF of $^1/_2$") glass-mat gypsum board embodies about 7.0 GJ of primary energy (LHV) and emits 437 kg CO_2 eq of greenhouse gases. Around 98% of the total primary energy is derived from non-renewable primary energy resource.

Across the three production information modules, *Module A1 extraction and upstream production* contributes *the largest share* of the LCIA and energy indicator results – accounting for between 42% (smog) and 69% (eutrophication) of the potential environmental burdens. The glass matting production is the primary contributor to *Module A1 Extraction and upstream production*. *Module A3 Manufacturing* is the second largest contributor (<50%) to the overall potential environmental impacts of ½" Regular glass-mat gypsum board manufacture. Except for acidification (31%) and smog potential impacts (37%), *Module A2 Transportation* is generally a minor contributor (<10%) to the overall potential environmental impacts of ½" Regular glass-mat gypsum board manufacture.

The cradle-to-gate manufacture of 92.9 m^2 of 15.9 mm (1 MSF of $^5/_8$") glass-mat gypsum board embodies about 8.1 GJ of primary energy (LHV) and emits 504 kg CO_2 eq of greenhouse gases. Around 98% of the total primary energy is derived from non-renewable primary energy resource.

Across the three production information modules, *Module A1 extraction and upstream production* contributes *the largest share* of the LCIA and energy indicator results – accounting for between 39% (smog) and 65% (eutrophication) of the potential environmental burdens. The glass matting production is the primary contributor to *Module A1 Extraction and upstream production*. *Module A3 Manufacturing* is the second largest contributor (<50%) to the overall potential environmental

impacts of 5/8"" Type X glass-mat gypsum board manufacture. Except for acidification (35%) and smog potential impacts (40%), *Module A2 Transportation* is generally a minor contributor (<10%) to the overall potential environmental impacts of 5/8"" Type X glass-mat gypsum board manufacture.

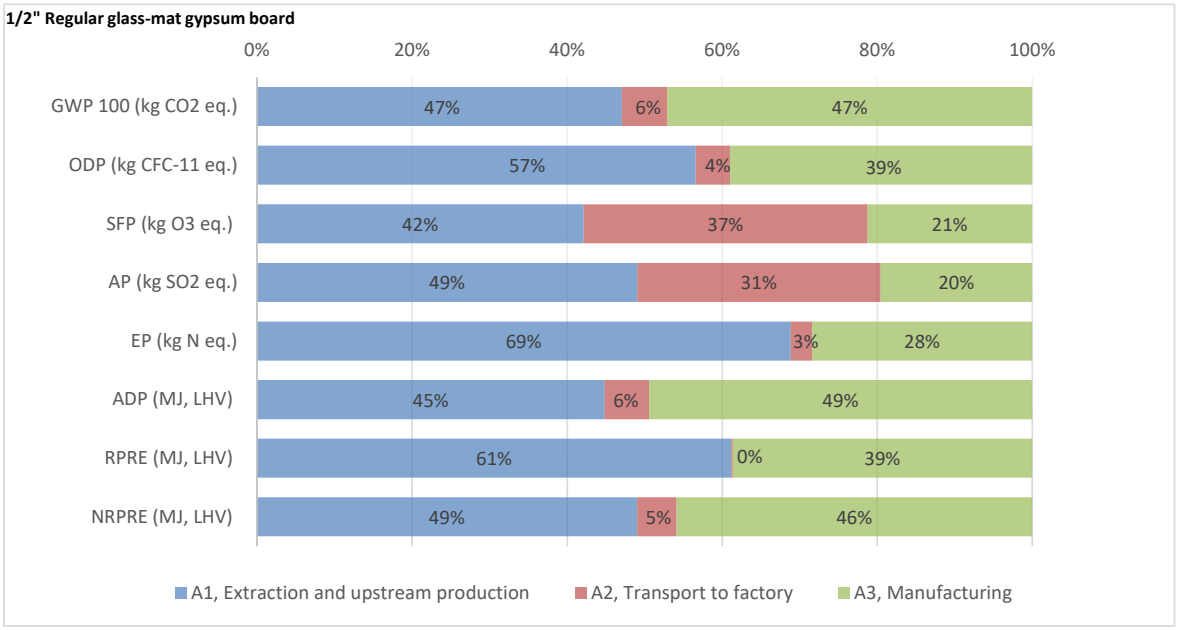


Figure 4 Impact assessment and energy indicator results by information module – 92.9 m² (1 MSF) of 1/2" Regular glass-mat gypsum board – % Basis

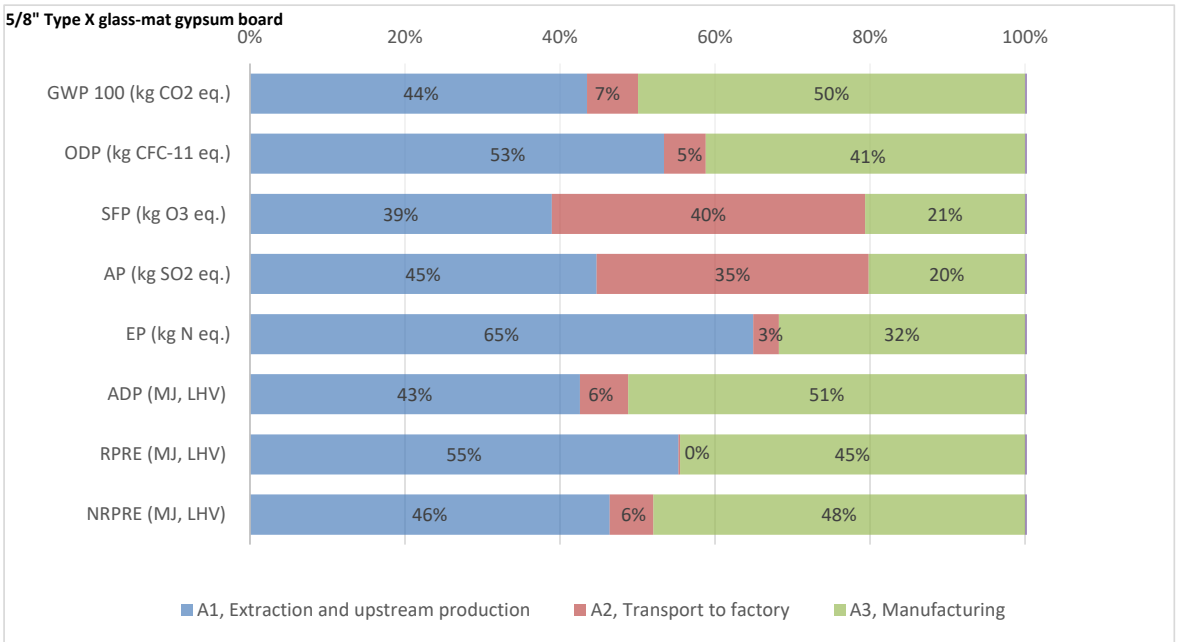


Figure 5 Impact assessment and energy indicator results by information module – 92.9 m² (1 MSF) of 5/8" Type X glass-mat gypsum boards – % Basis

Table 8 presents a dominance analysis, indicating the top four inputs or processes contributing to the global warming potential (GWP_{100}) result. In descending order, the upstream manufacture of glass mat, on-site natural gas and electricity consumption during manufacturing, followed by the transportation of inputs are the four major GWP_{100} sources – accounting for over 90% of the greenhouse gases emitted during the production stage.

Table 9 Production Stage (A1-A3), GWP_{100} dominance analysis – 92.9 m^2 (1 MSF) of 1/2" Regular and 5/8" Type X glass-mat gypsum boards

Production Stage (A1 to A3)	1/2" Regular glass-mat gypsum board		5/8" Type X glass-mat gypsum board	
	kg CO_2 eq.	%	kg CO_2 eq.	%
Glass matting production, A1	176	41%	182	36%
On-site natural gas consumption (natural gas processing and combustion), A3	162	37%	198	39%
On-site electricity consumption (electricity generation and transmission), A3	36	8%	45	9%
Transportation, A2	26	6%	33	7%
Rest of processes, A1 to A3	35	8%	44	9%
Total	**437**	**100%**	**504**	**100%**

7.2 Completeness, Consistency, and Sensitivity Checks

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" Regular and **5/8"** Type X glass-mat gypsum board systems were checked for data completeness. All input and output data were found to be complete, and no gaps were identified at information modules A1, A2 and A3 (see Annex A, B and C).

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 glass-mat 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 Sections 5, and Annex B, Tables B1, B2, and B3). Table 3 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 procedure of ***sensitivity analysis*** 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 shown in Tables C2 and C3, Annex B, US Electricity grid mix *(Electricity, medium voltage {US}| market group for | Cut-off, U) and* US Natural gas mix *(Heat, district or industrial, natural gas {US}| market for heat, district or industrial, natural gas | Cut-off, U) LCI datasets* are consistently used for all *foreground* (natural gypsum extraction and glass-mat gypsum board manufacturing) *and background* LCI datasets listed in Annex C, Table C1, as applicable.

Table B1, Annex B and Tables C2 and C3, Annex C, are provided for transparency, to allow for *consistent and transparent industry wide comparability and benchmarking of EPDs*, while maintaining *data confidentiality* (GA plant/site specific market share data) [16]. This allows GA manufactures to accurately meet the LEED v4 and/or v4.1, MR Credit: Building Product Disclosure and Optimization – Environmental Product Declarations, *Option 2 Multi-attribute optimization* (1 point) [17], [18].

Scenario analysis was conducted to illustrate the consequences of replacing US electricity grid and natural gas mix (see above) with the *weighted average* electricity grid and natural gas LCI profiles for natural gypsum extraction and glass-mat gypsum board manufacturing (foreground processes only). *It should be noted that the GA plant/site names and locations are known to all GA members, as a result of the GA LCA team discussions on the industry wide plant sample representativeness*. To protect GA plant/site specific market share data, the *weighted average LCI profiles* for electricity grid and natural gas for natural gypsum extraction and glass-mat gypsum board cannot be presented in the project report, but it is calculated and used for the purposes of the scenario analysis.

The scenario analysis results are presented in detail in Tables 10 and 11 for both ½" Regular and **$^{5}/_{8}$"** Type X glass-mat gypsum board systems. 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 (see Tables 10 and 11). For example, the influence of this scenario to GWP_{100} of the **$^{5}/_{8}$"** Type X glass-mat gypsum board compared to the base case is positive (+0.6%) and indicates a 0.6% higher GWP compared to the base case. *The scenario analysis shows that the weighted average LCI profiles for electricity grid and natural gas (for foreground processes only) were deemed not significant sensitivity scenario (less than 1% change, except for RPR_E* (2%) and EP (5%*) for the LCIA and energy indicators for both ½" Regular and $^{5}/_{8}$" Type X glass-mat gypsum board systems.*

Table 10 Scenario analysis results (*Production stage*)- 92.9 m² (1 MSF) of ½" Regular glass-mat gypsum board

LCIA and energy indicators	Base case	Scenario case	Deviation-in absolute basis	Deviation-in %
GWP (kg CO_2 eq.)	437.4	439.8	2.3	0.5%
ODP (kg CFC-11 eq.)	7.19E-05	7.21E-05	2.1E-07	0.3%
SFP (kg O_3 eq.)	29.9	29.8	-0.1	-0.3%
AP (kg SO_2 eq.)	1.6	1.6	-0.004	-0.2%
EP (kg N eq.)	1.0	1.0	0.044	4.6%
ADP (MJ surplus)	910	917	7.5	0.8%
RPR_E (MJ, LHV)	160	157	-3.0	-1.9%
$NRPR_E$ (MJ, LHV)	6,806	6,831	25	0.4%

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

Table 11 Scenario analysis results (*Production stage*)- 92.9 m² (1 MSF) of $^5/_8$" Type X glass-mat gypsum board

LCIA and energy indicators	Base case	Scenario case	Deviation-in absolute basis	Deviation-in %
GWP (kg CO_2 eq.)	503.9	506.8	2.9	0.6%
ODP (kg CFC-11 eq.)	8.30E-05	8.33E-05	2.5E-07	0.3%
SFP (kg O_3 eq.)	35.7	35.6	-0.1	-0.3%
AP (kg SO_2 eq.)	2.0	1.9	-0.005	-0.2%
EP (kg N eq.)	1.1	1.1	0.055	5.2%
ADP (MJ surplus)	1,072	1,081	9.3	0.9%
RPR_E (MJ, LHV)	179	175	-3.7	-2.1%
$NRPR_E$ (MJ, LHV)	7,958	7,988.4	31	0.4%

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

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 (see Annex D).

Based on the industry sample data, [minimum; maximum] range data was calculated per each input/output flow for the two selected foreground product systems (natural gypsum extraction and glass-mat gypsum board manufacturing). These data are used in the Monte Carlo uncertainty analysis. *This uncertainty analysis assesses the combined uncertainty effect of the inventory data (both foreground and background)*-see Annexes A to C. *It should be noted that U.S. EPA TRACI v2.1 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 the uncertainty range, which expresses the variance between the upper and lower confidence limit [97.5%, 2.5%], in the calculated LCA results (Figures D1 and D2, Annex D). *Based on 1,000 runs, such information provides a quantitative indication of the range of results that are likely for the*

manufacturer's specific products covered by the industry average EPD for two selected glass-mat 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* is beneficial for the glass-mat gypsum board industry as it reduces the dependency on primary material resources (natural gypsum ore).
- Across the three production stage information modules, *Modules A1 and A3*, contribute the largest share of the LCIA category and energy indicator results – together accounting for between 60% (smog) and 97% (eutrophication) of the potential environmental burdens for both ½" Regular and **5/8"** Type X glass-mat gypsum board systems.
- Over 98% of the total primary energy is derived from *non-renewable primary energy resource* for both ½ Regular and 5/8" Type X glass-mat gypsum board systems.
- On-site *natural gas and electricity consumption* (Module A3) accounted for greater than 45% of the GWP_{100} indicator results. Glass matting production (Module A1) accounted for around 40% of the GWP_{100} indicator results.

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* [3].
The GA gypsum board manufacturing facilities produce other co-products besides selected glass-mat 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 **5/8"** Type X glass-mat gypsum board products.
Based on the EPD results "on-site" energy conservation efforts at glass-mat manufacturing facilities are strongly recommended. The EPD study results indicate that "on-site" energy use is the single largest contributor to the cradle-to gate EPD results. More specifically, efforts to reduce natural gas use offer the most immediate opportunity to improve the environmental performance of glass-mat gypsum board plants and products.

8 Additional Environmental Information

- *GWP 100a indicator results per IPCC 2013 AR5 and IPCC 2007 (AR4)*

TRACI v2.1 was originally based on IPCC 2007 AR4 GWP 100a factors. IPCC 2013 AR5 is the successor of the IPCC 2007 AR4 method. Table 12 shows cradle-to-gate GWP 100a indicator results per IPCC 2013 AR5 and IPCC 2007 AR4 for 92.9 m^2 (1 MSF) of ½" Regular and 5/8" Type X glass-mat gypsum boards.

Table 12 Product Stage (A1-A3), GWP 100a indicator results per IPCC 2013 (AR5) and 2007 (AR4) – 92.9 m² (1 MSF) of ½" Regular and 5/8" Type X glass-mat gypsum boards

GHGs	Unit	1/2" Regular glass-mat gypsum board		5/8" Type X glass-mat gypsum board	
		GWP 100a IPCC 2013 (AR5)[1)]	GWP 100a IPCC 2007 (AR4)[2)]	GWP 100a IPCC 2013 (AR5)[1)]	GWP 100a IPCC 2007 (AR4)[2)]
GWP 100a	kg CO_2 eq.	**437.4**	**431.7**	**503.9**	**497.2**

Note:
[1)] The GWP 100a per IPCC 2013 AR5 (in kg CO_2 eq.): CO_2=1; CH_4, fossil=30; CH_4, biogenic=28; N_2O=265.
[2)] The GWP 100a per IPCC 2007 AR4 (in kg CO_2 eq.): CO_2=1; CH_4, fossil =25; CH_4, biogenic=22.25; N_2O=298.
[3)] Data are rounded to four (4) significant digits.

- 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, accessed 30-03-2021.
No additional health protection measures extending beyond mandatory occupational safety measures for commercial operations are required.

- *Environmental Protection Manufacture and Equipment*

The GA member manufacturing facilities comply with the regional (U.S. and Canadian) 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, accessed 30-03-2021.
- The Canadian National Pollutant Release Inventory (NPRI) reporting
http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1, accessed 30-03-2021.

Pollution abatement equipment typically used in the glass-mat gypsum board manufacturing facilities are as follows: fabric filter – high temperature (baghouse), fabric filter- low temperature (baghouse), bin vent filter, drum filter, dry filter, cartridge filter, precipitator and water sprinkler for dust control.

9 Declaration Type and Product Average Declaration

The type of EPD based on this Project Report is defined as:
- A "*Cradle-to-gate*" EPD for ½" Regular and $^5/_8$" Type X glass-mat gypsum boards covering the *Production stage* (information modules A1 to A3) and is intended for use in *Business-to-Business* communication.

GA EPD of glass-mat gypsum boards UNSPSC Code 30161500 falls under the description:
- An average product EPD, as an average from several GA manufacturers' facilities
(in this case, GA member manufacturers as listed under "GA Member Companies Corporate Locations", see pg. 2).

10 Declaration Comparability Limitation Statement

The following ISO 21930 statement indicates the EPD comparability limitations and intent to avoid any market distortions or misinterpretation of EPDs based on the NSF PCR for Gypsum Panel Products [5]:

> - *Only EPDs prepared from cradle-to-grave life cycle results and based on the same function, 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 comparison between products*.

11 EPD Explanatory Material

For any explanatory material, regarding the GA EPD for glass-mat gypsum boards based on this Project Report, please contact the program operator.

ASTM International
Environmental Product Declarations
100 Barr Harbor Drive,
West Conshohocken,
PA 19428-2959, http://www.astm.org

12 References

1. ASTM C1177/C1177M- 17 Standard Specification for Glass Mat Gypsum Substrate for Use as Sheathing
2. ISO 21930:2017 Sustainability in buildings and civil engineering works - Core rules for environmental product declarations of construction products and services.
3. ISO 14040:2006/Amd 1:2020 Environmental management - Life cycle assessment - Principles and framework.
4. ISO 14044:2006/Amd1:2017/Amd2:2020 Environmental management - Life cycle assessment - Requirements and guidelines.
5 NSF International, Product Category Rule Environmental Product Declarations, PCR for Gypsum Panel Products, April 2020.
6 ASTM Program Operator Rules. Version: 8.0, Revised 04/29/20.
7 ISO 14025:2006 Environmental labeling and declarations - Type III environmental declarations - Principles and procedures.
8. ASTM C11 – 18b Standard Terminology Relating to Gypsum and Related Building Materials and Systems.
9. ISO 14021:2016 Environmental labels and declarations - Self-declared environmental claims (Type II environmental labelling).
10. US EPA 2014, Coal Combustion Residual Beneficial Use Evaluation: Fly Ash Concrete and FGD Gypsum Wallboard, Office of Solid Waste and Emergency Response, Office of Resource Conservation and Recovery, U.S. Environmental Protection Agency, EPA530-R-14-001, https://www.epa.gov/sites/production/files/2014-12/documents/ccr_bu_eval.pdf, accessed 30-03-2021.
11. US EPA 2008, Waste and Materials-Flow Benchmark Sector Report: Beneficial Use of Secondary Materials - Coal Combustion Products. Economics, Methods, and Risk Analysis Division, Office of Solid Waste, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, https://nepis.epa.gov/Exe/ZyPDF.cgi/P1005STJ.PDF?Dockey=P1005STJ.PDF, accessed 30-03-2021.
12. BOKELA 2017/2018, Vacuum Drum Filters for Dewatering of FGD-Gypsum. http://www.bokela.de/uploads/media/BOKELA_drum_filter-prosp_en.pdf, accessed 30-03-2021.
13. Bruce G. Miller, 5 Anatomy of a Coal-Fired Power Plant, Clean Coal Engineering Technology (Second Edition), 2017, https://doi.org/10.1016/B978-0-12-811365-3.00005-3, accessed 30-03-2021.
14. PRé 2019.SimaPro LCA Software v9.1.1.1, 2021, https://simapro.com/, accessed 30-03-2021.
15. ACLCA 2019, Guidance to Calculating Non-LCIA Inventory Metrics in Accordance with ISO 21930:2017. The American Centre for Life Cycle Assessment. May, 2019, https://aclca.org/aclca-iso-21930-guidance/, accessed 30-03-2021.
16. USGBC 2017, PCR Committee Process & Resources- Part B, https://www.usgbc.org/resources/pcr-committee-process-resources-part-b, accessed 30-03-2021.
17. LEED v4, *Building Design and Construction Guide (BD+C), MR Credit: Building Product Disclosure and Optimization – Environmental Product Declarations, Option 2 Multi-attribute optimization* (1 point). https://www.usgbc.org/node/2616376?return=/credits/new-construction/v4/material-%26amp%3B-resources, accessed 30-03-2021.
18. LEED v4.1 July 2019, *Building Design and Construction Guide (BD+C), Getting started guide for beta participant, MR Credit: Building Product Disclosure and Optimization – Environmental Product Declarations, Option 2 Multi-attribute optimization (1 point), pg.170.* https://new.usgbc.org/leed-v41, accessed 30-03-2021.