Athena Sustainable Materials Institute

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An Industry Average Cradle-to-Gate Life Cycle Assessment of 1/2" Lightweight and 5/8" Type X Conventional 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: NSF Certification LLC

April 2020

General Summary

This life cycle assessment (LCA) report presents industry average results for $^{1}/_{2}$" Lightweight (regular core) and $^{5}/_{8}$" Type X conventional (type X core) gypsum boards as produced by Gypsum Association members in the US and Canada. The LCA has been conducted to support a Type III Environmental Product Declaration (EPD) for $^{5}/_{8}$" Type X conventional gypsum board conforming to ASTM C1396, Standard Specification for Gypsum Board [1][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 NSF 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 NSF 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)** 6525 Belcrest Road, Suite 480 Hyattsville, MD 20782 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. To be eligible for membership in the Association, a firm or corporation must calcine gypsum and manufacture gypsum board under the provisions of ASTM Standard C1396. Each GA member company provided both LCI and meta-data for the reference year 2017. GA members, with the

[1] While this LCA Background Report covers both products it is the Gypsum Association's intent to only produce an industry average EPD for $^{5}/_{8}$" Type X conventional gypsum board.

General Summary	
	inclusion of their Canadian holdings and affiliates, produce and ship over 90% of the gypsum board 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 Company LLC 3811 Turtle Creek Blvd., Suite 1200 Dallas, TX 75219, USA Member Link (URL): http://www.americangypsum.com/
	CertainTeed Gypsum, Inc. CertainTeed Gypsum Canada, Inc. 20 Moores Road Malvern, PA 19355, USA Member Link (URL): http://www.certainteed.com/gypsum
	Continental Building Products 12950 Worldgate Drive, Suite 700 Herndon, VA 20170, USA Member Link (URL): http://www.continental-bp.com/en/
	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/

General Summary	
	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	Gypsum board
Product Description	Gypsum board is the generic name for a family of sheet products consisting of a non-combustible core primarily of gypsum with a paper facing [5], [8] (UNCPC Code 3699, NAICS Code 327420). Conventional $^{5}/_{8}$" Type X gypsum board greater thickness and special core additives provides additional fire resistance, higher rigidity and enhanced sound attenuation as compared to $^{1}/_{2}$" Lightweight gypsum board.
Product Category Rules (PCR)	NSF International, Product Category Rule for Environmental Product Declarations, PCR for Gypsum Panel Products, April 2020 [5].
Certification Period	28.04.2020 - 27.04.2025
Declared Unit	92.9 m^2 (1,000 square feet) of $^{1}/_{2}$" (12.7 mm) Lightweight and $^{5}/_{8}$" (15.9 mm) Type X conventional gypsum board.
NSF Declaration Number	EPD 10270

EPD and Project Report Information			
Program Operator		NSF Certification, LLC	
Declaration Holder		Gypsum Association (GA)	
Product group	**Date of Issue**	**Period of Validity**	**Declaration Number**
Gypsum board	28.04.2020	5 years	EPD 10270

Declaration Type

A "cradle-to-gate" EPD for $^{5}/_{8}$" Type X conventional gypsum board 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

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*; *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 NSF in accordance with ISO 14025 and the reference PCR: **Internal** **External** X	 Jenny Oorbeck, joorbeck@nsf.org
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 $^{1}/_{2}$" Lightweight and $^{5}/_{8}$" Type X conventional Gypsum Board for the USA and Canadian Markets, April 2020.
Prepared by	Lindita Bushi, Ph.D. and Mr. Jamie Meil Athena Sustainable Materials Institute 280 Albert Street, Suite 404 Ottawa, Ontario, Canada K1P 5G8 info@athenasmi.org www.athenasmi.org

EPD and Project Report Information	
This EPD project report was independently verified by in accordance with ISO 14025, ISO 14040/44, and the reference PCR:	 Jack Geibig – EcoForm jgeibig@ecoform.com
PCR Information	
Program Operator	NSF Certification, LLC
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 14040/44:2006 [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: Set of criteria specifying which unit processes are part of a product system. Note: the term system boundary is not used in this International Standard in relation to LCIA.

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.

Gypsum board: The generic name for a family of sheet products consisting of a non-combustible core primarily of gypsum with paper facing [8].

Gypsum panel products: The general name for a family of sheet products consisting essentially of gypsum [8].

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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
GB	Gypsum board
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
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 systems, reward building projects across the LEED rating systems (BD+C, ID+C, ND, and Homes)[2], 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 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 gypsum boards and in support of generating an environmental product declaration for $^{5}/_{8}$" (15.9 mm) Type X conventional gypsum board as produced in the USA and Canada.

In support of the study, primary LCI data were collected for three major gate-to-gate processes in the production of gypsum board: natural or crude gypsum ore extraction (six quarries and one

[2] 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).
https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-healthca-22?return=/credits/new-construction%20/v4/material-&-resources, accessed 15-04-2020.
LEED v4.1, MR Credit 2, EPDs- Option 1 (similar to v4): 1 point.
https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-162, accessed 15-04-2020.

underground mining site), gypsum face and backing paper manufacture (three plants) and gypsum board production (17 plants) for the reference year 2017. The gypsum board manufacturing plant study sample included all GA member companies and represented about 25% of all establishments producing gypsum and about 30% of all gypsum board produced in the N.A. To ensure representativeness, the gypsum board manufacturing plant study also 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).

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], NSF PCR [5], and ISO 21930 [2] for $^{5}/_{8}$" (15.9 mm) Type X conventional gypsum board, 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

The industry average EPD for $^{5}/_{8}$" Type X conventional gypsum board based on 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 is independently verified by Jack Geibig, EcoForm, in accordance with ISO 14025 [7], ISO 14040/44 [3], [4], and the NSF PCR requirements [5].

3 Product Identification

3.1 Product Description

Gypsum boards (UN CPC Code 3699, NAICS Code 327420), are manufactured to ASTM C1396 [1] and are designed to be used as an interior sheathing capable of supporting an array of finishes and demonstrating various performance characteristics. Per NSF PCR [5], *gypsum board* is the generic name for a family of sheet products consisting of a non-combustible core primarily of gypsum with paper facing [8]. 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*, *sheet rock* and *gypsum panel*. The substrates consist of a noncombustible water-resistant gypsum core, sandwiched between two layers of paper. Typically, gypsum boards are 4' wide and 8' length panels (4'×8') produced with a beveled edge and are compatible with most interior wall and ceiling applications. Gypsum board may be available in other lengths and can vary in thickness and fire rating properties depending on types of additives.
The focus of this industry average LCA study for EPD is on two gypsum board products:

- $^{1}/_{2}$" (12.7 mm) Lightweight gypsum board (regular core); and
- $^{5}/_{8}$" (15.9 mm) Type X conventional gypsum board (type X core).

As calculated, the weighted average density of $^{5}/_{8}$" Type X conventional gypsum board (MC 0%) was 10.4 kg/m^2, with a minimum and maximum density value of 9.9 and 11.0 kg/m^2, respectively (less than +/-10% variation). It should be noted that $^{5}/_{8}$" Type X conventional gypsum board (type X core) does not cover $^{5}/_{8}$" Mold and Moisture Resistant (MMR), including paper faced abuse resistant, paper faced impact resistant (fiberglass mesh reinforcement embedded in the core) and paper faced plaster base gypsum board.

Similarly, the weighted average density of $^{1}/_{2}$" Lightweight gypsum board (MC 0%) was determined to be 6.6 kg/m^2, with a minimum and maximum density value of 6.2 and 7.3 kg/m^2 (MC 0%), respectively (less than +/-10% variation). $^{1}/_{2}$" Lightweight gypsum board (regular core) does not cover $^{1}/_{2}$" MMR or conventional weight board. These two selected products represent about 80% of all gypsum board products produced in North America. $^{1}/_{2}$" (12.7 mm) Lightweight gypsum board is more typically used in *residential* applications while $^{5}/_{8}$" (15.9 mm) 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 light weighting. Lightweighting has been more pronounced in the manufacture of $^{1}/_{2}$" 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 of gypsum board.

Figure 1 Gypsum board [Photo Courtesy: FPInnovations, 2014]

3.2 Product Standard

Applicable product standards for gypsum board (UN CPC Code 3699, NAICS Code 327420) include:

- ASTM C11–18b *Standard 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 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 E84–19b *Standard Test Method for Surface Burning Characteristics of Building Materials*.
- ASTM E119–18ce1 *Standard 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 for 92.9 m^2 (one thousand square feet, 1 MSF) of $^1/_2$" Lightweight and $^5/_8$" Type X conventional gypsum boards by input material as derived from the GA member facilities LCI data for the reference year 2017. The final weight of each board type includes chemically bounded water.

Table 1 Weighted average material content for 92.9 m² (1 MSF) of gypsum board by thickness

Inputs	½" Lightweight	5/8" Type X conventional	Units
Natural gypsum ore	182	359	kg
FGD synthetic gypsum	383	558	kg
Post-consumer gypsum[1)]	4.2	3.5	kg
Facing paper	22.7	19.2	kg
Backing paper	17.7	17.9	kg
Starch	4.7	3.8	kg
Vermiculite	0	0.55	kg
Fiberglass	0.52	2.65	kg
Potash	0.16	0.0041	kg
Dextrose	0.36	0.59	kg
Dispersant	1.46	1.63	kg
Retarder	0.24	0.22	kg
Potassium Sulfate	0.022	0.020	kg
Clay, kaolin	0	0.28	kg
Boric Acid	0.36	0.12	kg
Foaming agent (soap)	0.27	0.25	kg
Ball mill accelerator, BMA	3.1	2.4	kg
Edge Paste	0.21	0.20	kg
Sodium Trimetaphosphate	0.27	0.036	kg
Shredded Paper	0.027	0.029	kg
Water	422	610	kg
Wet weight	972	1461	kg
Final weight, with MC	*635*	*991*	*kg*
Final MC	2.7%	2.6%	%
Final weight, with 0% MC	*618*	*964*	*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).

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 1/2" Lightweight and 5/8" Type X conventional gypsum board (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

Name	½" Lightweight	5/8" Type X conventional	Units
Declared unit	92.9	92.9	m^2
Mass	635	991	kg
Thickness	12.7	15.9	mm
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 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 and 4 illustrate the system boundary for natural gypsum ore extraction and gypsum paper production, respectively. Figure 5 presents the *Production stage* system boundary for the declared 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 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, 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, 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.

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 weighted average transportation data up to the recycler or disposal.

No energy recovered from secondary fuels and/or waste combustion is used in natural gypsum ore extraction, gypsum paper production or gypsum board manufacturing processes.

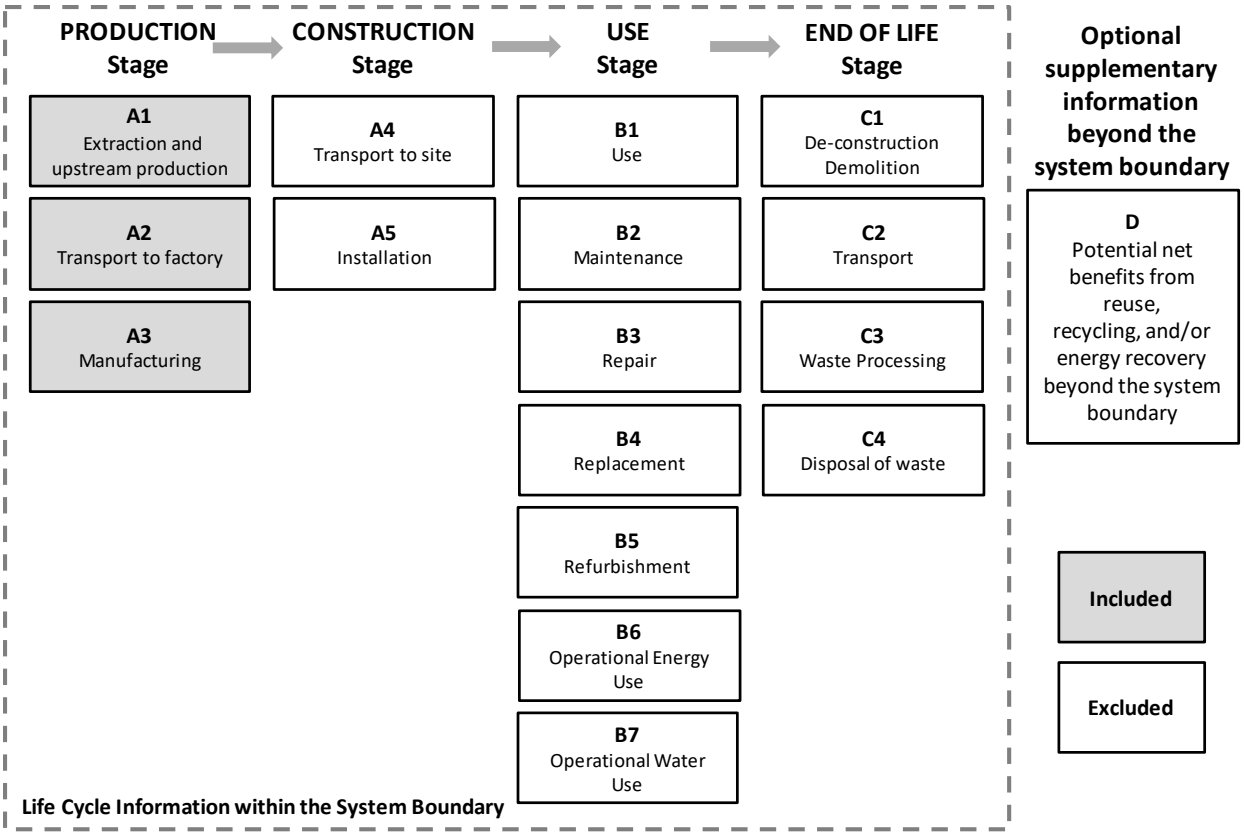

Figure 2 Common four life cycle stages and their information modules for construction products and the optional supplementary module [2]

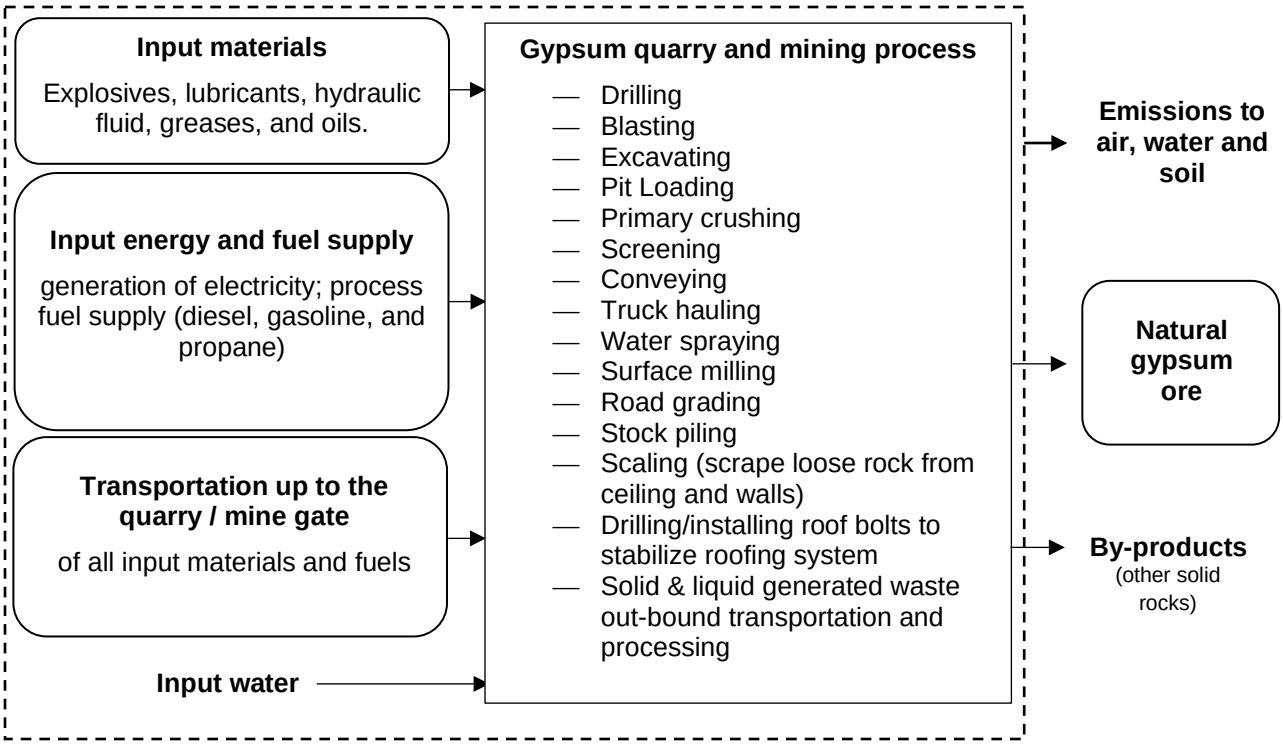

Figure 3 Cradle-to-gate system boundary of natural gypsum ore extraction, included in Module A1

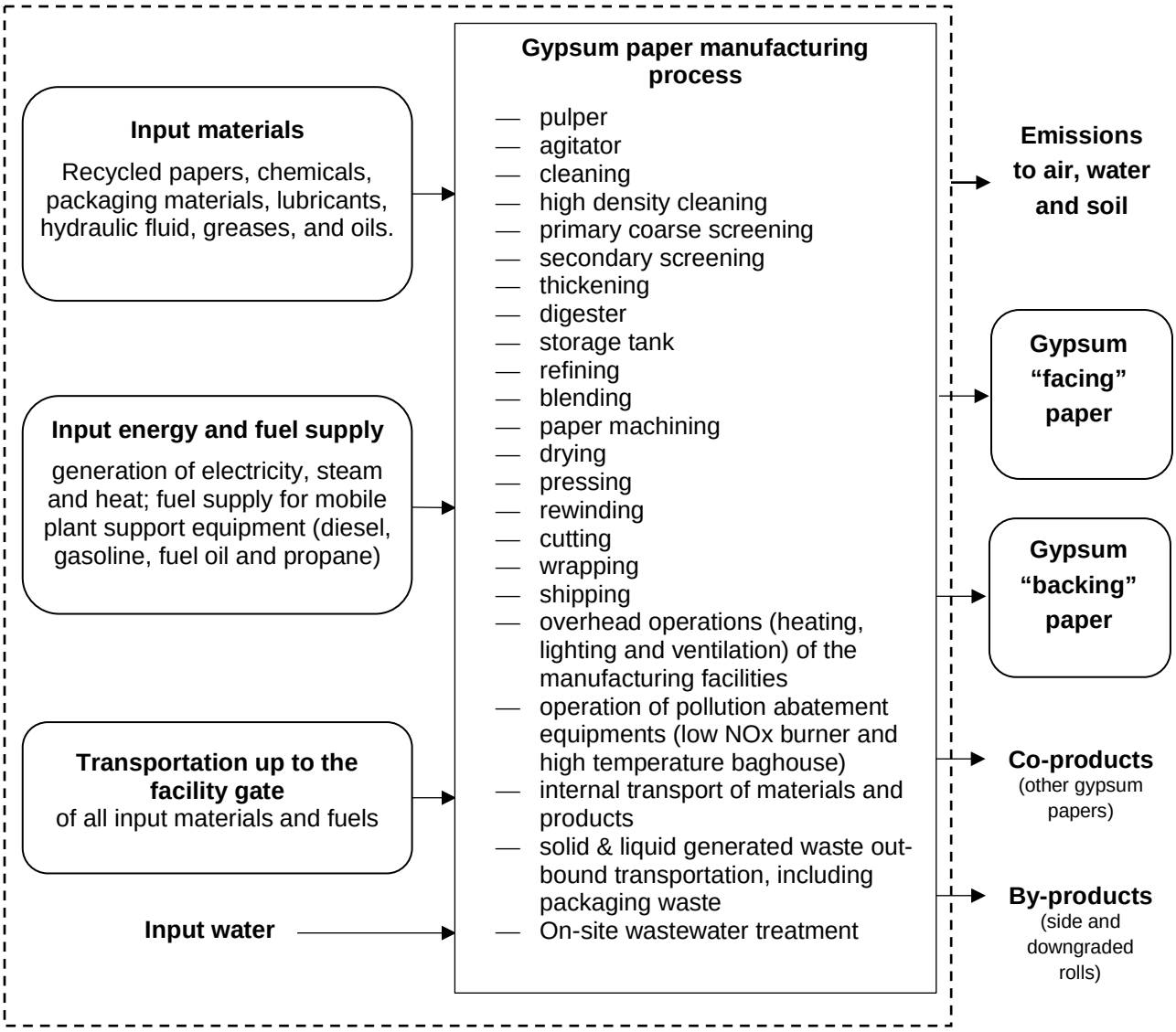

Figure 4 Cradle-to-gate system boundary of gypsum paper manufacturing, included in Module A1

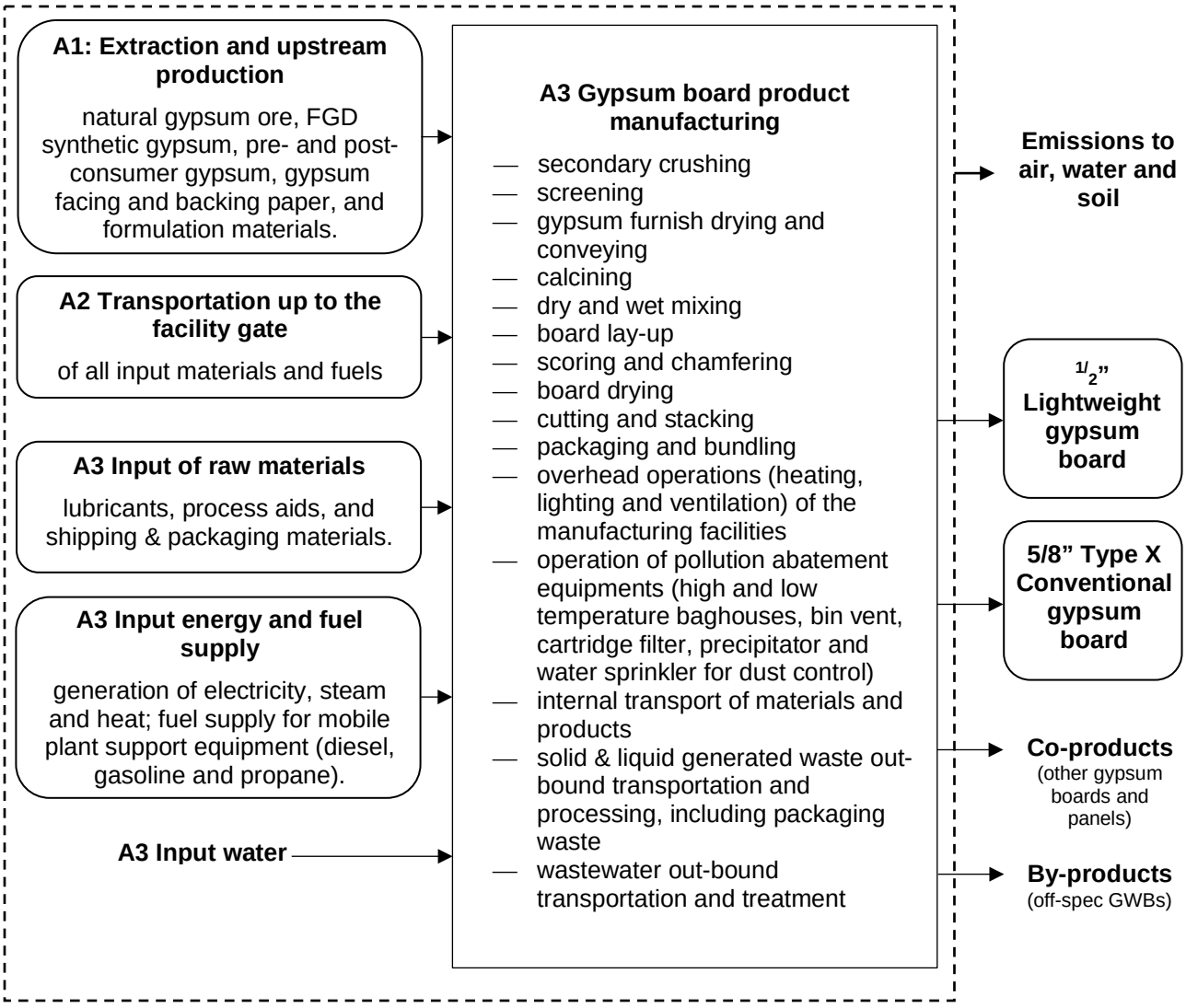

Figure 5 Production stage (modules A1 to A3) system boundary of gypsum board manufacturing

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 and B). 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 2017 e.g. input hydraulic fluids, lubricants, oils, or packaging materials 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. sizing agents, retention 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 B, Table B1 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);
- 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.9.0.0.30 2020 (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 v3.5 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 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 17 facilities operated by the 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 a third of all GA member facilities producing gypsum board.

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. 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. Described below is the GA's well-defined plant selection platform for inclusion in the industry-average study sample.

- In 2017, about 51 GB manufacturing plants were operating in the US and Canada.

- Of these, 17 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 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 sources of FGD synthetic gypsum were also included in the sample. A minimum amount of FGD synthetic gypsum (less than 1% of the total FGD) is also imported (location is not specified for confidentiality reasons, as less than three plants used imported FGD synthetic gypsum in 2017 reference year).

In addition, in the framework of this project, foreground gate-to-gate LCI data were collected for natural gypsum ore extraction (six quarries and one underground mining site) as well the manufacture of gypsum facing and backing papers (three plants) for the reference year 2017.

LCI data collection was based on three customized LCI surveys for the GA natural gypsum ore extraction sites, gypsum paper production, and gypsum board manufacturing facilities. The LCI survey covered the following *primary data* for each facility for the 2017 reference:

- 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*;

Annex A, Tables A1, A2 and A3 summarize the 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 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 module (A1, A2, A3). Trucking is the primary mode of transport for all input/output flows followed by rail, barge and ship.
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 the natural gypsum ore (in short ton), gypsum papers (per MSF) and gypsum boards (per MSF)- see Annex A, Tables A9, A10 and A11. *Table A12* 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 2010 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 C).
This LCA study draws on appropriate LCI datasets provided by (see Annexes A and B):

- Gypsum Association and its members on natural gypsum ore extraction, gypsum paper production and gypsum board manufacturing (see Annex A, Table A1 to A8); and
- 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 3.5, allocation, cut-off database, 2018 (http://www.ecoinvent.org/). Both are included in the LCA software SimaPro v.9.0.0.30 2020.

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, 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 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 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 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 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 B, Table B1 to B3). *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 B, Tables B1 to B3. *Geographical representativeness is characterized as "high".*
Time Coverage	Activity data are representative as of 2017 (see Annex A, Tables A1 to A7). - Gypsum board manufacturing process- primary data collected from 17 facilities: reference year 2017 (12 months); - In-bound/ out-bound transportation data- primary data collected from 17 facilities: reference year 2017 (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.3.5 database for US, Canada and global, 2018. US LCI database "dummies" (empty/missing LCI datasets) are substituted with ecoinvent v3.5 LCI datasets. *Temporal representativeness is characterized as "high".*

Data Quality Requirements	Description
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 1/2" (12.7 mm) Lightweight and 5/8" (15.9 mm) Type X conventional gypsum board. The relevant background materials and processes were taken from the US LCI Database (adjusted for known data placeholders), ecoinvent v 3.5 LCI database for US and Canada, and modeled in SimaPro software v.9.0.0.30, 2020. The completeness of the cradle-to-gate process chain 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, fomulation, 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 GB LCI database* developed in SimaPro, 2019. 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 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 LCI datasets are transparently disclosed in the project 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

Per NSF PCR, Section 7.2.3 and 7.2.6 [5], *allocation, if required, shall follow the requirements and guidance of ISO 14044:2006, 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 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, 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 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 1).
Per 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. Similarly, plant specific generic formulations for 1 MSF (92.9 m^2) of gypsum paper and *mass* was used as the basis for allocating flows across products and *co-products* of gypsum paper manufacturing.

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); *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 out to other converters to make tubes and cores), or *other rocks* from gypsum ore extraction sites (sold to other industries), see Figures 3, 4 and 5, and Tables A1, A2 and A3.
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 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 gypsum board products [10], [11]. For FGD synthetic gypsum to be a saleable product for use in 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 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 GB 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 Product Manufacturing Life Cycle Inventory

The cradle-to-gate weighted average LCI model considers the three modules: A1 Extraction and upstream production, A2 Transport to factory and A3 Manufacturing of each selected gypsum board products.

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 be 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/flyleaves, 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 continuous 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 equipments 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 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 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 equipments included in the gate-to-gate system boundaries for gypsum board manufacturing process. The production 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 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
	ADP LHV	MJ, LHV	CML-baseline, v4.7 August 2016	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 product 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 $^1/_2$" Lightweight and $^5/_8$" Type X conventional gypsum boards. (Tables 6 and 7). *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 6 Product Stage (A1-A3), EPD Results – 92.9 m² (1 MSF) of 1/2" Lightweight gypsum board

Impact category and inventory indicators	Unit	A1, Extraction and upstream production	A2, Transport to factory	A3, Manufacturing	Total
Global warming potential, GWP 100[1)], AR5	kg CO_2 eq	51.2	9.6	145.8	**207**
Ozone depletion potential, ODP[1)]	kg CFC-11 eq	5.7E-06	6.3E-10	1.9E-05	**2.5E-05**
Smog formation potential, SFP[1)]	kg O_3 eq	2.20	3.93	3.50	**9.6**
Acidification potential, AP[1)]	kg SO_2 eq	0.163	0.14	0.24	**0.54**
Eutrophication potential, EP[1)]	kg N eq	0.245	0.0081	0.24	**0.49**
ADP surplus, TRACI[2)]	MJ surplus	91.8	19.2	315.1	**426**
ADP LHV, CML[3)]	MJ LHV	643.1	129.6	2,076	**2,849**
Renewable primary resources used as an energy carrier (fuel), RPR_E	MJ LHV	144.4	0	37	**182**
Renewable primary resources with energy content used as material, RPR_M[4)]	MJ LHV	0	0	0	**0**
Non-renewable primary resources used as an energy carrier (fuel), $NRPR_E$	MJ LHV	705.3	131.0	2201	**3,037**
Non-renewable primary resources with energy content used as material, $NRPR_M$[5)]	MJ LHV	0	0	0	**0**
Secondary materials, SM[6)]	kg	433	0	0	**433**
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	0.433	0	0.51	**0.94**
Hazardous waste disposed, HWD[11)]	kg	0	0	0	**0**
Non-hazardous waste disposed, NHWD[12)]	kg	4.7330	0	4.1	**8.9**
High-level radioactive waste, conditioned, to final repository, HLRW[13)]	m^3	3.4E-08	8.0E-12	7.5E-08	**1.1E-07**
Intermediate- and low-level radioactive waste, conditioned, to final repository, ILLRW[14)]	m^3	4.4E-07	6.4E-11	6.2E-07	**1.1E-06**
Components for re-use, CRU[15)]	kg	0	0	0	**0**
Materials for recycling, MR[16)]	kg	0	0	21.3	**21.3**
Materials for energy recovery, MER[17)]	kg	0	0	0	**0**
Recovered energy exported from the product system, EE[18)]	MJ LHV	0	0	0	**0**

Table 7 Product Stage (A1-A3), EPD Results – 92.9 m² (1 MSF) of 5/8" Type X conventional gypsum board

Impact category and inventory indicators	Unit	A1, Extraction and upstream production	A2, Transport to factory	A3, Manufacturing	Total
Global warming potential, GWP 100[1)], AR5	kg CO_2 eq	55.5	9.9	211.6	**277**
Ozone depletion potential, ODP[1)]	kg CFC-11 eq	6.0E-06	8.0E-10	2.8E-05	**3.4E-05**
Smog formation potential, SFP[1)]	kg O_3 eq	2.91	3.71	5.15	**11.8**
Acidification potential, AP[1)]	kg SO_2 eq	0.189	0.14	0.35	**0.67**
Eutrophication potential, EP[1)]	kg N eq	0.250	0.0079	0.34	**0.60**
ADP surplus, TRACI[2)]	MJ surplus	97.6	19.9	457.4	**575**
ADP LHV, CML[3)]	MJ LHV	697.1	134.4	3,014	**3,845**
Renewable primary resources used as an energy carrier (fuel), RPR_E	MJ LHV	129.2	0	55	**184**
Renewable primary resources with energy content used as material, RPR_M[4)]	MJ LHV	0	0	0	**0**
Non-renewable primary resources used as an energy carrier (fuel), $NRPR_E$	MJ LHV	770.8	135.8	3194	**4,100**
Non-renewable primary resources with energy content used as material, $NRPR_M$[5)]	MJ LHV	0	0	0	**0**
Secondary materials, SM[6)]	kg	608	0	0	**608**
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	0.443	0	0.78	**1.22**
Hazardous waste disposed, HWD[11)]	kg	0	0	0	**0**
Non-hazardous waste disposed, NHWD[12)]	kg	4.7349	0	5.9	**10.6**
High-level radioactive waste, conditioned, to final repository, HLRW[13)]	m^3	4.1E-08	1.3E-11	1.1E-07	**1.5E-07**
Intermediate- and low-level radioactive waste, conditioned, to final repository, ILLRW[14)]	m^3	4.3E-07	1.0E-10	9.1E-07	**1.3E-06**
Components for re-use, CRU[15)]	kg	0	0	0	**0**
Materials for recycling, MR[16)]	kg	0	0	28.3	**28.3**
Materials for energy recovery, MER[17)]	kg	0	0	0	**0**
Recovered energy exported from the product system, EE[18)]	MJ LHV	0	0	0	**0**

Notes to Tables 6 and 7:

[1)] Calculated as per U.S EPA TRACI v2.1, with IPCC 2013 (AR 5), SimaPro v 9 [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].

Notes to Tables 6 and 7, Continued:

[2)] 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].

[3)] Calculated as per CML-IA Baseline V3.05, SimaPro v 9 [14]. ADP LHV, CML is also 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.* N/A for the gypsum boards.

[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 for the gypsum boards.

[6)] Calculated as per ACLCA ISO 21930 Guidance [15], 6.5 Secondary materials, SM; it includes post-consumer gypsum, synthetic gypsum (FGD), and mixed waste papers used in gypsum paper manufacturing.

[7)] Calculated as per ACLCA ISO 21930 Guidance [15], 6.6 *Renewable secondary fuels, RSF*. N/A for the gypsum boards.

[8)] Calculated as per ACLCA ISO 21930 Guidance [15], 6.7 *Non-renewable secondary fuels, NRSF*. N/A for the gypsum boards.

[9)] Calculated as per ACLCA ISO 21930 Guidance [15], 6.8 *Recovered energy, RE*. N/A for the gypsum boards.

[10)] Calculated as per ACLCA ISO 21930 Guidance [15], 9 *Inventory indicators describing consumption of freshwater*. It's calculated from 2017 industry average primary data for consumption of freshwater based solely on the foreground system (raw gypsum extraction, gypsum paper, and gypsum boards manufacturing processes).

[11)] Calculated as per ACLCA ISO 21930 Guidance [15], 10.1 *Hazardous waste disposed*. It's calculated from 2017 industry average primary data for hazardous waste disposed based solely on the foreground system (raw gypsum extraction, gypsum paper, and gypsum boards manufacturing processes).

[12)] Calculated as per ACLCA ISO 21930 Guidance [15], 10.2 *Non-hazardous waste disposed*. It's calculated from 2017 industry average primary data for non-hazardous waste disposed based solely on the foreground system (raw gypsum extraction, gypsum paper, and 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 gypsum board foreground system (raw gypsum extraction, gypsum paper, and 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 gypsum board foreground system (raw gypsum extraction, gypsum paper, and 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 for the gypsum boards.

[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 for the gypsum boards.

[18)] Calculated as per ACLCA ISO 21930 Guidance [15], 10.8 *Recovered energy exported from the system*. N/A for the gypsum boards.

[19)] Note that data may not add up to totals due to rounding.

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

Per NSF PCR, 7.2.7 [5], for the gypsum panel products, recycled raw materials used to produce paper are not counted as biogenic carbon whereas starch and dextrose are counted. Table 8 shows the cradle-to-gate biogenic CO_2 removals associated with bio-based products used in the gypsum board system.

Table 8 Production Stage (A1-A3), Biogenic CO_2 removals – 92.9 m^2 (1 MSF) of 1/2" Lightweight and 5/8" Type X conventional

Inputs	Chemical formula	C-Content (in %)	Biogenic CO_2 removals (in kg CO_2/ MSF)	
			½" Lightweight	5/8" Type X conventional
Starch	$(C_6H_{10}O_5)_n$	44%	**- 7.6** = -4.7 kg × 0.44 × (44/12)	**- 6.1** = -3.8 kg×0.44×(44/12)
Dextrose	$C_6H_{12}O_6$	40%	**- 1.2** = -(0.36+0.47) kg × 0.40 × (44/12)	**- 1.4** = -(0.59+0.36) 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 that is applied directly to the board (not part of BMA, Table 1), and 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;
- *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 $^1/_2$" Lightweight and $^5/_8$" Type X conventional 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 $^1/_2$") Lightweight gypsum board*** embodies about 3.2 GJ of primary energy (LHV) and emits in the order of 207 kg CO_2 eq of greenhouse gases. Around 95% of the total primary energy is derived from non-renewable primary energy resource.

Across the three-gypsum board production information modules, *Module A3 Manufacturing*, contributes *the largest share* of the LCIA and energy indicator results – accounting for between 36% (smog) and 77% (ozone depletion) of the potential environmental burdens. *Module A1 Extraction and upstream production* is the second largest contributor (<50%) to the overall potential environmental impacts of ½" Lightweight gypsum board manufacture. Except for acidification (26%) and smog potential impacts (41%), *Module A2 Transportation* is generally a minor contributor (<5%) to the overall potential environmental impacts of ½" Lightweight gypsum board manufacture.

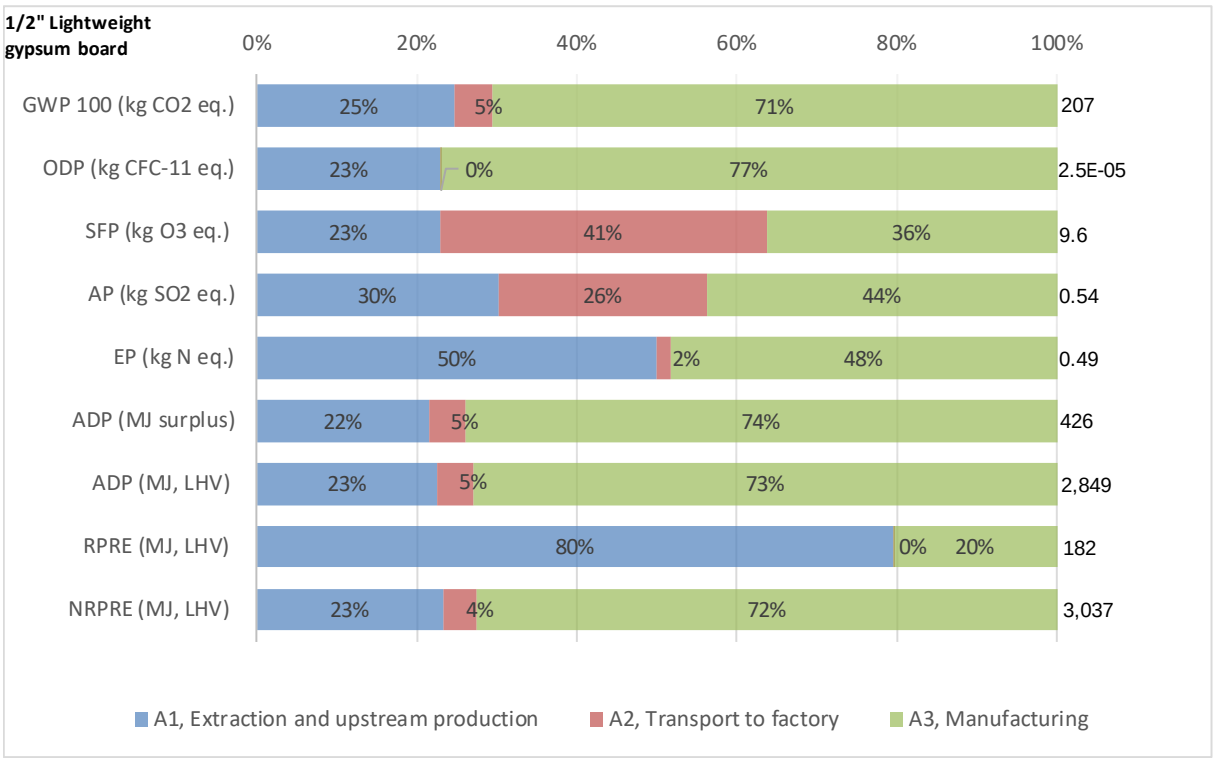

Figure 6 Impact assessment and energy indicator results by information module – 92.9 m^2 (1 MSF) of $^1/_2$" Lightweight gypsum board– % Basis

The cradle-to-gate manufacture of ***92.9 m² of 15.9 mm (1 MSF of 5/8") Type X conventional gypsum board*** embodies about 4.3 GJ of primary energy (LHV) and emits in the order of 277 kg CO_2 eq of greenhouse gases. Over 95% of the total primary energy is derived from non-renewable primary energy resources.

Across the three-gypsum board production information modules, *Module A3 Manufacturing*, contributes the largest share of the LCIA and energy indicator results – accounting for between 44% (smog) and 82% (ozone depletion) of the potential environmental burdens. *Module A1 Extraction and upstream production* is the second largest contributor (<42%) to the overall potential environmental impacts of ½" Lightweight gypsum board manufacture. Except for acidification (20%) and smog potential impacts (32%), *Module A2 Transportation* is generally a minor contributor (<4%) to the overall impact of 5/8" Type X gypsum board manufacture.

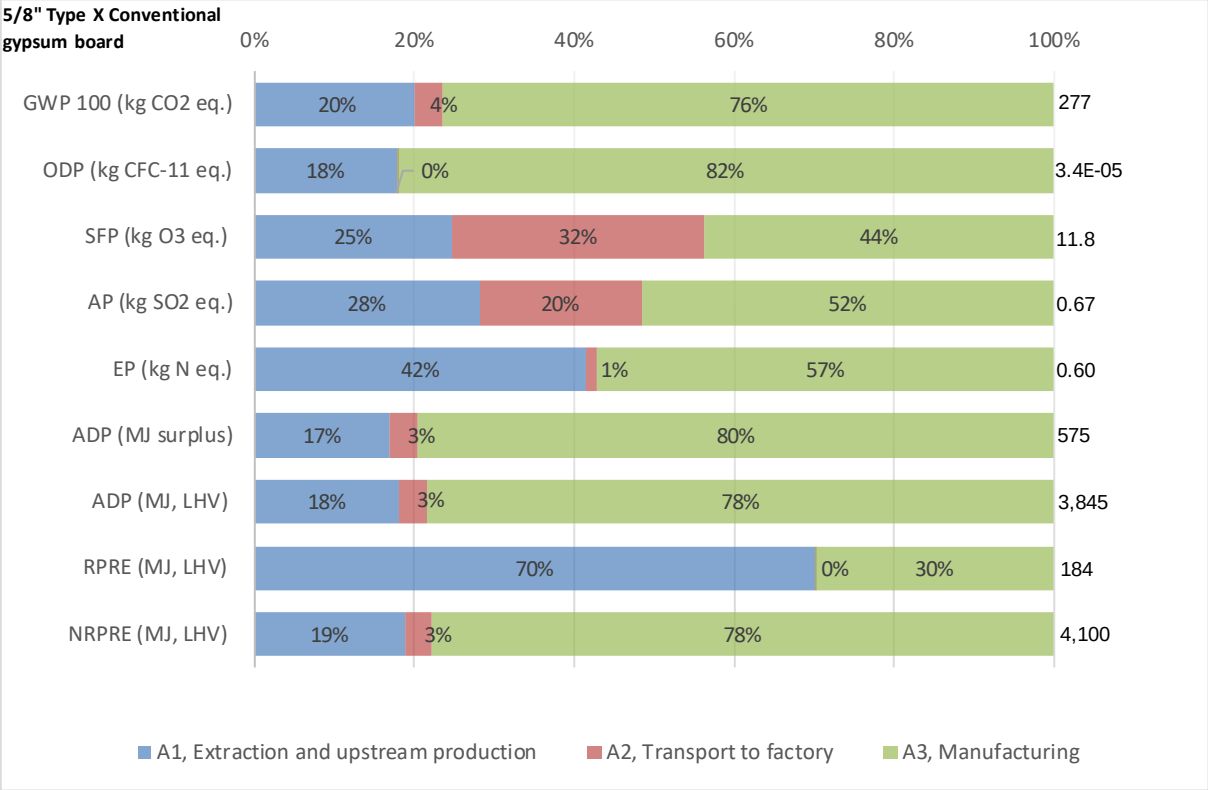

Figure 7 Impact assessment and energy indicator results by information module – 92.9 m² (1 MSF) of 5/8" Type X conventional gypsum board – % Basis

Furthermore, Figures 8 and 9 illustrate the results of the *process contribution analysis* for 92.9 m² (1 MSF) of ½" Lightweight and ***5/8***" Type X conventional gypsum board products. The *process contribution analysis* shows that the *three main inputs* of the gypsum board manufacturing system are, in descending order, *on-site natural gas consumption*, *gypsum paper, and on-site electricity consumption*.

As shown in Table A3, *natural gas and electricity* were the two major input energy flows used in the production of gypsum boards. While the electricity is used at all manufacturing unit processes

most of the natural gas is used during the drying of the input gypsum, calcining or stucco production and drying the final board product. ***On-site natural gas and electricity consumption (A3 module) accounted for greater than 70% of the GWP 100 and NRPR$_E$ indicator results***. Except for RPR$_E$ (13%), the contribution to the rest of the EPD results ranged from 31% to 82% of the total potential impact results for the two selected board products.

Facing and backing gypsum papers' contribution (A1 module) ranged from 10% to 26% of the total potential impact results for both ½" Lightweight and $^5/_8$" Type X conventional.
Except for EP (22%) and RPR$_E$ (73%), formulation materials' contribution (A1 module) ranged from 3% to 12% of the total potential impact results for the ½" Lightweight. Similarly, except for EP (18%) and RPR$_E$ (63%), formulation materials' contribution ranged from 3% to 11% of the total potential impact results for the ***$^5/_8$***" Type X conventional. *Starch* accounts for over 30% by mass of the total input weight of formulation materials and dominated the total potential impact results of formulation materials between 25% and 73%.
Extraction and upstream production of gypsum material (A1 module) is a minor contributor (<8%) to the overall potential environmental impacts for both ½" Lightweight and $^5/_8$" Type X conventional. The contribution of *packaging materials* (A3 module) resulted to less than 1% across all selected LCIA and energy indicators, apart from RPR$_E$ (7% and 11%) for ½" Lightweight and $^5/_8$" Type X conventional, respectively.

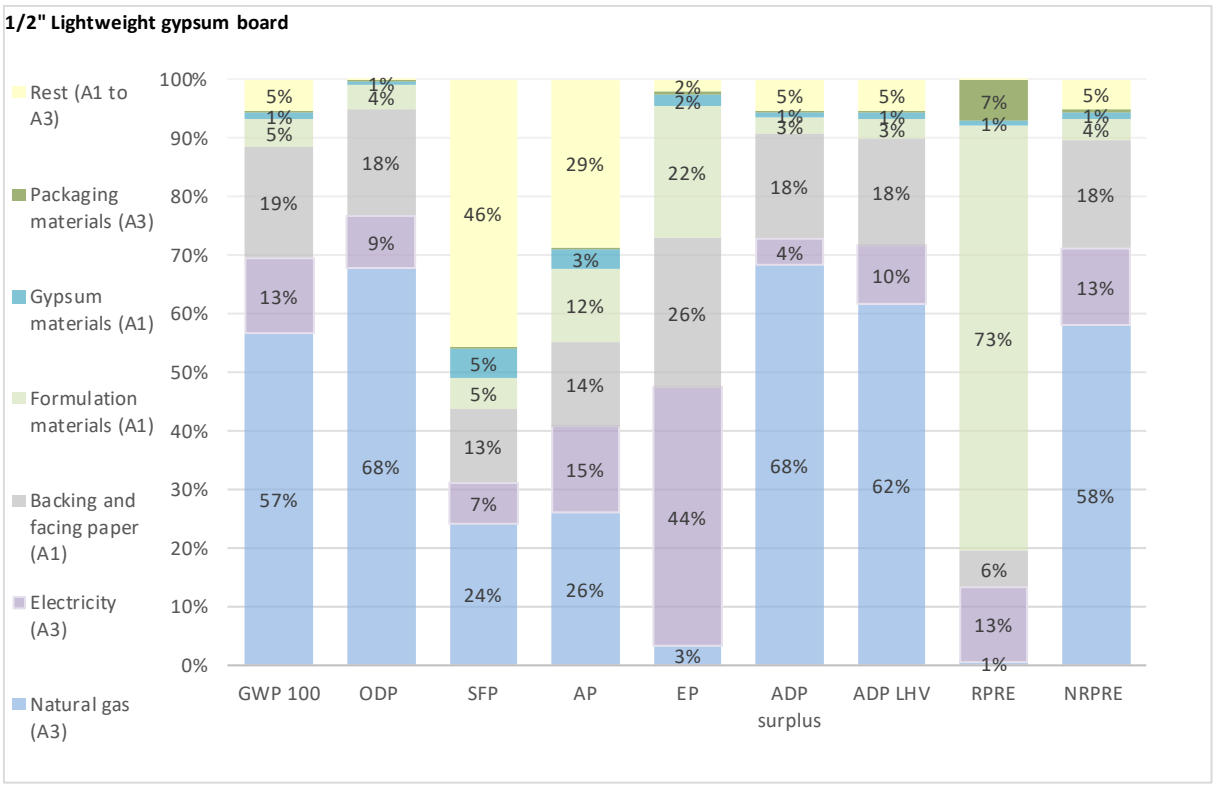

Figure 8 Process Dominance Analysis – 92.9 m^2 (1 MSF) of $^1/_2$" Lightweight gypsum board – % Basis

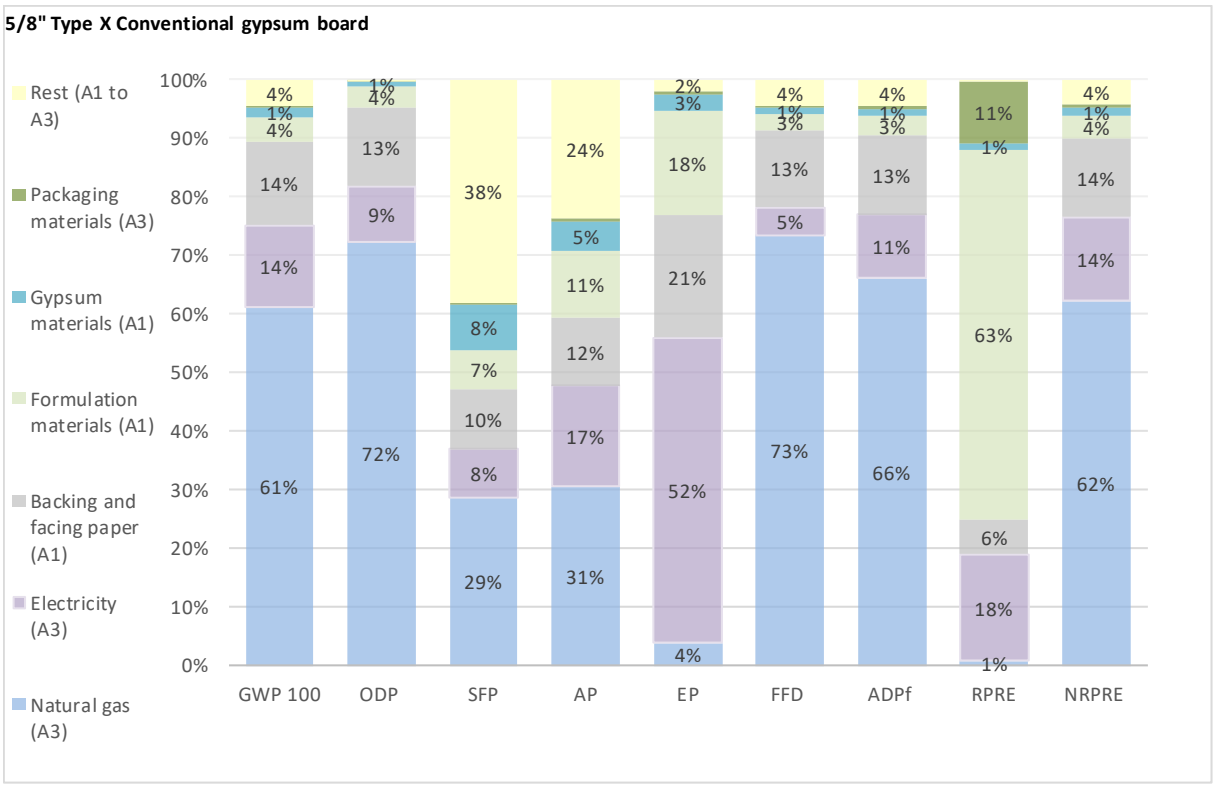

Figure 9 Process Dominance Analysis – 92.9 m² (1 MSF) of 5/8" Type X conventional gypsum board – % Basis

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" Lightweight and **5/8"** 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 at information modules A1, A2 and A3 (see Tables A1, A2, A3, A4, A5, A6, A7, Annex A and Table B1, Annex B).

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 Sections 5, and Tables B1, B2, and B3, Annex B). 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 B2 and B3, 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, gypsum paper production and gypsum board manufacturing) *and background* LCI datasets listed in Annex B, Table B1, as applicable.

Tables B2 and B3, Annex B, 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* electricty grid and natural gas LCI profiles for natural gypsum extraction, gypsum paper production and 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 representativenes*. To protect GA plant/site specific market share data, the *weighted average LCI profiles* for electricty grid and natural gas for natural gypsum extraction, gypsum paper and gypsum board can <u>not</u> 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 9 and 10 for both ½" Lightweight and **$^{5}/_{8}$"** Type X conventional 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 9 and 10). For example, the influence of this scenario to GWP 100 of the **$^{5}/_{8}$"** Type X Conventional compared to the base case is positive (+0.3%) and indicates a 0.3% 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 <u>not significant</u> sensitivity scenario (less than 1% change, except for RPR_E* (2 to 3%)*) for the LCIA and energy indicators for both ½" Lightweight and **$^{5}/_{8}$"** Type X conventional gypsum board systems.*

Table 9 Scenario analysis results (*Production stage*)- 92.9 m² (1 MSF) of ½" Lightweight

LCIA and energy indicators	Base case	Scenario case	Deviation-in absolute basis	Deviation-in %
GWP 100 (kg CO_2 eq.)	206.6	207.8	1.2	0.6%
ODP (kg CFC-11 eq.)	2.5E-05	2.5E-05	2.5E-07	1.0%
SFP (kg O_3 eq.)	9.6	9.7	0.1	0.6%
AP (kg SO_2 eq.)	0.54	0.54	1.6E-03	0.3%
EP (kg N eq.)	0.49	0.49	-8.2E-04	-0.2%
ADP (MJ surplus)	426	429	3	0.7%
ADP (MJ, LHV)	2,849	2,863	14	0.5%
RPR_E (MJ, LHV)	182	185	3	1.6%
$NRPR_E$ (MJ, LHV)	3,037	3,063	26	0.9%

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

Table 10 Scenario analysis results (*Production stage*)- 92.9 m² (1 MSF) of $^5/_8$" Type X conventional

LCIA and energy indicators	Base case	Scenario case	Deviation-in absolute basis	Deviation-in %
GWP 100 (kg CO_2 eq.)	277.0	277.9	0.9	0.3%
ODP (kg CFC-11 eq.)	3.4E-05	3.4E-05	2.9E-07	0.9%
SFP (kg O_3 eq.)	11.8	11.8	0.1	0.4%
AP (kg SO_2 eq.)	0.67	0.67	-1.2E-03	-0.2%
EP (kg N eq.)	0.60	0.60	-6.1E-03	-1.0%
ADP (MJ surplus)	575	579	4	0.6%
ADP (MJ, LHV)	3,845	3,859	14	0.4%
RPR_E (MJ, LHV)	184	190	5	2.9%
$NRPR_E$ (MJ, LHV)	4,100	4,128	27	0.7%

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

Sensitivity analysis was also conducted on *on-site natural gas consumption* at the GB plants – by far the most significant contributor to the EPD results for both product systems.

The coefficient of variation (COV) of the on-site natural consumption factor per 92.9 m² (MSF) of gypsum board products was calculated to be approximately 25%. 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 25% change in natural gas consumption would have on the LCIA and energy indicator results in the production of **$^5/_8$"** Type X conventional gypsum board products. The sensitivity analysis results are presented in Table 11 for **$^5/_8$"** Type X conventional gypsum board. The sensitivity analysis indicate that a 25% change in plant natural gas consumption would result in around 15% change in GWP 100 and $NRPR_E$ for 5/8" Type X conventional.

For best identification of *significant* sensitivity parameters (SP), sensitivity is calculated as the ratio (R_{SP}) of the percent change in LCA indicator result over the percent change in the parameter value. The sensitivity analysis shows that the natural gas consumption factor is deemed *significant sensitivity parameter* (R_{SP} = 0.6). Similar findings are applicable for the ½" Lightweight.

Table 11 Sensitivity analysis results (*Production stage*)- 92.9 m² (1 MSF) of 5/8" Type X conventional

LCIA and energy indicators	Base case	Scenario case_25% increase	Scenario case_25% decrease	Deviation- in absolute basis (+/-)	Deviation- in % (+/-)
GWP 100 (kg CO_2 eq.)	277	319	235	42	**15.3%**
ODP (kg CFC-11 eq.)	3.4E-05	4.0E-05	2.7E-05	0	18%
SFP (kg O_3 eq.)	11.8	12.6	10.9	1	7%
AP (kg SO_2 eq.)	0.67	0.72	0.62	0	8%
EP (kg N eq.)	0.60	0.61	0.60	0	1%
ADP (MJ surplus)	575	680	469	105	18%
ADP (MJ, LHV)	3,845	4,480	3,210	635	17%
RPR_E (MJ, LHV)	184	185	184	0	0.2%
$NRPR_E$ (MJ, LHV)	4,100	4,737	3,464	637	**15.5%**

[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 C).
Based on the industry sample data, [minimum; maximum] range data was calculated per each input/output flow for the three selected foreground product systems (natural gypsum extraction, gypsum paper production, and gypsum board manufacturing). This 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 and B. *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 C1 and C2, Annex C). *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 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* is beneficial for the gypsum board industry as it reduces the dependency on primary material resources (natural gypsum ore and virgin paper stock).
- Across the three-gypsum board production information modules, *Module A3 Manufacturing*, contributes the largest share of the LCIA category indicator results – accounting for between 36% (smog) and 82% (ozone depletion) of the potential environmental burdens for both ½" Lightweight and **⅝"** Type X conventional gypsum board systems.
- Around 95% of the total primary energy is derived from *non-renewable primary energy resource* for both both ½" Lightweight and **⅝"** Type X conventional gypsum board systems.
- On-site *natural gas and electricity consumption* (A3 Manufacturing) accounted for greater than 70% of the GWP 100 and $NRPR_E$ indicator results. Except for RPR_E (13%), the contribution to the rest of the EPD results ranged from 31% to 82% of the total potential impact results for the two selected board products.
- *Facing and backing gypsum papers'* contribution (A1 Extraction and upstream production) ranged from 10% to 26% of the total potential impact results for both ½" Lightweight and 5/8" Type X conventional.

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 gypsum boards and as such allocation based on the mass of gypsum board products was necessary. This methodological approach is excepted 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 gate 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

- *GWP 100a indicator results per IPCC 2013 AR5 and IPCC 2007 (AR4)*
  TRACI v2.1 was originally based on IPCC 2007 AR4 100a GWP 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, IPCC 2007 AR4, and major GHG emissions for 92.9 m^2 (1 MSF) of ½" Lightweight and $^5/_8$" Type X conventional.

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

GHGs	Unit	1/2" Lightweight		5/8" Type X conventional	
		GWP 100a IPCC 2013 (AR5)[1)]	GWP 100a IPCC 2007 (AR4)[2)]	GWP 100a IPCC 2013 (AR5)[1)]	GWP 100a IPCC 2007 (AR4)[2)]
Carbon dioxide (CO_2), fossil	kg CO_2 eq.	182	182	245	245
Methane (CH_4), fossil	kg CO_2 eq.	19	16	27	22
Dinitrogen monoxide (N_2O)	kg CO_2 eq.	2.8	3.1	3.2	3.6
Methane, biogenic	kg CO_2 eq.	2.0	1.6	2.0	1.6
Rest (GHGs)	kg CO_2 eq.	0.2	0.2	0.3	0.3
Total	kg CO_2 eq.	**207**	**204**	**277**	**273**

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

- *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 15-04-2020.
  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 15-04-2020.
  - The Canadian National Pollutant Release Inventory (NPRI) reporting

http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1, accessed 15-04-2020.

Pollution abatement equipments 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.

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 $^{5}/_{8}$" Type X conventional gypsum board covering the *Production stage* (information modules A1 to A3) and is intended for use in *Business-to-Business* communication.

GA EPD for $^{5}/_{8}$" Type X conventional gypsum board (*UNCPC Code 3699, NAICS Code 327420)* 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. III-IV).

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 Gypsum boards based on this Project Report, please contact the program operator.

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12 References

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3. ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework.
4. ISO 14044:2006 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 NSF Program Operator Rules. February 2015. https://www.nsf.org/newsroom_pdf/NSF_Program_Operator_Instructions-news.pdf, accessed 15-04-2020.
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).
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