This project report and its results are used to support the development of an industry wide or sector average Environmental Product Declaration for the production of 72 concrete mix designs

Commissioner: National Ready Mixed Concrete Association (NRMCA)

EPD Program Operator: NSF International

Prepared by: The Athena Sustainable Materials Institute

October 2016
Glossary of Terms

Based on ISO 14040/44:2006 – Terms and Definition Section [1].

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.

Life Cycle: Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.

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

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

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

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

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

System boundary: 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.

System expansion: Expanding the product system to include the additional functions related to the co-products, taking into account the requirements of 4.2.3.3.

Based on ISO 14021:1999(E): Clause 7.8 Recycled content

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.
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.

Building product: goods or services used during the life cycle of a building or other construction works.

Declared unit: quantity of a building product for use as a reference unit in an EPD, based on LCA, for the expression of environmental information needed in information modules.

Information module: compilation of data to be used as a basis for a type III environmental declaration, covering a unit process or a combination of unit processes that are part of the life cycle of a product.

Reference service life: service life of a building product that is known or expected under a particular set, i.e., a reference set, of in-use conditions and that may form the basis of estimating the service life under other in-use conditions.
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**Acronyms and Abbreviations**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACI</td>
<td>American Concrete Institute</td>
</tr>
<tr>
<td>Btu</td>
<td>British thermal units</td>
</tr>
<tr>
<td>C2G</td>
<td>Cradle-to-Gate</td>
</tr>
<tr>
<td>CED</td>
<td>Cumulative Energy Demand</td>
</tr>
<tr>
<td>CF</td>
<td>Characterization Factor</td>
</tr>
<tr>
<td>CFCs</td>
<td>Chlorofluorocarbons</td>
</tr>
<tr>
<td>CFC-11</td>
<td>Trichlorofluoromethane</td>
</tr>
<tr>
<td>CLF</td>
<td>Carbon Leadership Forum</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>EPDs</td>
<td>Environmental Product Declarations</td>
</tr>
<tr>
<td>eq</td>
<td>Equivalent</td>
</tr>
<tr>
<td>G2G</td>
<td>Gate-to-Gate</td>
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<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
</tr>
<tr>
<td>HHV</td>
<td>Higher Heating Value</td>
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<tr>
<td>IC</td>
<td>Impact Categories</td>
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<tr>
<td>IPCC</td>
<td>International Panel on Climate Change</td>
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<td>ISO</td>
<td>International Organization for Standardization</td>
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<tr>
<td>kg</td>
<td>Kilogram</td>
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<tr>
<td>kJ</td>
<td>Kilojoules</td>
</tr>
<tr>
<td>km</td>
<td>Kilometer</td>
</tr>
<tr>
<td>kWh</td>
<td>Kilowatt hours</td>
</tr>
<tr>
<td>lbs</td>
<td>Pounds</td>
</tr>
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<td>LCIA</td>
<td>Life Cycle Impact Assessment</td>
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<tr>
<td>MJ</td>
<td>Mega joule</td>
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<tr>
<td>m³</td>
<td>Cubic meter</td>
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<tr>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>NRMCA</td>
<td>National Ready Mixed Concrete Association</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Nitrogen Oxides</td>
</tr>
<tr>
<td>O₃</td>
<td>Ozone</td>
</tr>
<tr>
<td>PCR</td>
<td>Product Category Rules</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>Particulate Matter less than or equal to 2.5 micrometers in diameter</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>Particulate Matter less than or equal to 10 micrometers in diameter</td>
</tr>
<tr>
<td>RMC</td>
<td>Ready-mixed concrete</td>
</tr>
<tr>
<td>SO₂</td>
<td>Sulfur dioxide</td>
</tr>
<tr>
<td>TRACI</td>
<td>Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts</td>
</tr>
<tr>
<td>US EPA</td>
<td>United States Environmental Protection Agency</td>
</tr>
<tr>
<td>VOCs</td>
<td>Volatile Organic Compounds</td>
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<tr>
<td>yd³</td>
<td>Cubic yard</td>
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1 General Study Aspects

<table>
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<td>External LCA Practitioner</td>
</tr>
<tr>
<td>Date/version</td>
</tr>
<tr>
<td>October 2016  Version 2.0</td>
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</table>

The LCA report is an update of the previously published Version 1.0. Updates to the LCA include additional study participants, more current background datasets, and additional lightweight concrete mixes. The LCA results in this document integrate the previous Version 1.0 participant data with the new participant data and updated model. This LCA document incorporates all of the content of the previous LCA and thus stands alone as the third party report for this project.

This study has been conducted in accordance with the requirements of the Carbon Leadership Forum (CLF) Product Category Rules (PCR) for ISO 14025 TYPE III Environmental Product Declarations (EPDs) for Concrete v1.1 (December 2013.) Further, this project report takes into consideration clarification notes 1, 2, and 3 issued by the CLF on April 10, 2014, July 17, 2014, and June 1, 2015 respectively. This study was also conducted in accordance with ISO 14040:2006, 14044:2006, 21930:2007. This study also follows the Program Operator Instructions of the NSF International from August 20th, 2014.

This project report has been commissioned with the intent to support a sector or industry wide Environmental Product Declaration (EPD) for ready-mixed concrete as produced by participating National Ready Mixed Concrete Association (NRMCA) members in accordance with ISO 14025 and the governing PCR.

This LCA project report was critically reviewed as per ISO 14040/44:2006 and the reference PCR requirements by Paula Bernstein, PRé. The critical review report and responses to review comments are available from the NRMCA upon request.

This life cycle assessment was independently verified in accordance with ISO 14044 and the reference PCR by:

Paula Bernstein, PRé North America
202-460-0280

2 Study Goal
This is a sector-driven initiative by NRMCA and its members to develop an industry wide EPD according to ISO 14025:2006 and specifically, the Carbon Leadership Forum PCR for ISO 14025 TYPE III EPDs for Concrete v1.1. The goal of this study is to provide information to support the development of an EPD for 72 ready-mixed concrete product ranges covering a significant portion of NRMCA member production.

2.1 Intended Applications
The EPD developed from this study is intended for use in Business to Business (B-to-B) communication.

2.2 Intended Audience
The intended audience for this LCA project report is NRMCA, its members and the verifier of the subsequent EPD. The intended audience for the EPD, for which this LCA project report serves as the reference document, include NRMCA 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 a range of ready-mixed concrete products.

Note: For purposes of USGBC LEEDv4 rating system EPD compliance only NRMCA member companies having participated in this industry average LCA and subsequent EPD may claim compliance with the rating system EPD contribution requirements. A list of NRMCA members and facilities participating in the development of this study is available from NRMCA and is appended to the EPD.

2.3 Comparative Assertions
This LCA project report does not include comparative assertions; however, it and the subsequent EPD may lead to future comparative studies intended to be disclosed to the public. LCAs and EPDs not covering all life cycle stages or based on a different PCR are examples of studies and EPDs offering limited comparability.
3 Study Scope

3.1 Product Standard
Products covered by this report satisfy general purpose concrete as used in residential, commercial and public works applications in the US and Canada. This EPD project report assesses the impacts for a range of ready-mixed concrete products in accordance with ASTM C94: Standard Specification for Ready-Mixed Concrete, ACI 318, Building Code Requirements for Structural Concrete, A23.1-09/A23.2-09 (R2014) - Concrete materials and methods of concrete construction/Test methods and standard practices for concrete, UNSPSC Code 30111500 Ready Mix and ACI 211.1: Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete.

3.2 System Boundary
The system boundary for this study is limited to a cradle-to-gate focus. The following three life cycle stages as per the governing PCR are included in the study scope (see Figure1):

A1- Raw material supply (upstream processes): extraction, handling, and processing of the raw materials and intermediate component products as well as fuels used in the production of concrete.
A2- Transportation: transportation of all input materials and fuels from the supplier to the gate of the concrete plant.
A3- Manufacturing (core process): the energy used to store, move, batch and mix the concrete and operate the concrete plant as well as the transportation and processing of wastes from these core processes.

Note: a significant portion of N. American concrete plants are truck-mixing (sometimes called transit mix) plants where the concrete mixing occurs within truck mixers after they are loaded and at the project site; for these operations a portion of the delivery truck’s energy use that would typically be captured under “Construction and Process Stage” A4-Transportation (to site) is allocated to the mixing of concrete for truck-mixing plants and is captured in information module A3. This system boundary refinement addresses the difference between truck-mixing and central mix concrete plants where the latter plant type fully mixes the concrete in a stationary plant mixer prior to loading the concrete delivery trucks. See the allocation section for more details.
### Building Life Cycle Information Modules

<table>
<thead>
<tr>
<th>Product stage</th>
<th>Construction stage</th>
<th>Use stage</th>
<th>End-of-life stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw Material supply</td>
<td>Process stage</td>
<td>Use stage</td>
</tr>
<tr>
<td>A1</td>
<td>A2</td>
<td>A3</td>
<td>A4</td>
</tr>
</tbody>
</table>

**Figure 1.** Life cycle stage schematic – alpha-numeric designations as per CLF PCR (adapted from CEN 15978:2011)

### 3.3 Declared Unit

The declared unit is 1 cubic meter and 1 cubic yard of ready mixed concrete.

Environmental impacts are provided for 72 ready mixed concrete (RMC) products (mix designs). There are 100s if not 1,000s of possible RMC products (sometimes called mix designs, mixes, mixture compositions or mixtures), which ultimately balance the cost and performance of concrete for a wide variety of applications. For purposes of the NRMCA member industrywide LCA and EPD, a conservative approach was taken to arrive at a workable list of 72 RMC products that could pragmatically represent a high proportion of the RMC produced by NRMCA members identified in the EPD. The typical process for developing mix designs is 1) a design professional or purchaser of concrete states a specified compressive strength and other performance criteria for the concrete, and 2) the concrete producer develops a mix design, or proportions, to meet the specified compressive strength and other performance criteria using an accepted mixture proportioning methodology such as the ACI recommended practice 211.1 and 211.2, the most common method used in North America. For the EPD, NRMCA provided the mix designs using the ACI 211.1 process. For normal weight concrete, six different commonly specified compressive strengths were selected and 8 different mixture compositions were developed for each specified compressive strength. Further, 8 different mixture compositions were developed for three different compressive strengths of lightweight concrete mixes. The total number of products is thus 72.

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3 American Concrete Institute 1998. Standard Practice for Selecting Proportions for Structural Lightweight Concrete. ACI 211.2-98. ACI Committee 211 Report
Each RMC product considers 28-day strength, water to cementitious materials ratio to meet the specified compressive strength, air-entrainment admixture, water reducing and accelerating admixture, high range water reducing admixture, coarse aggregate size and reactivity of supplementary cementitious materials as a percentage of portland cement reactivity. The key product variables are briefly described below:

- **28-day strength** – Six different specified compressive strengths were considered for normal weight concrete, 2,500 psi (17.3 MPa), 3,000 psi (20.7 MPa), 4,000 psi (27.6 MPa), 5,000 psi (34.5 MPa), 6,000 psi (41.3 MPa) and 8,000 psi (55.1 MPa); Three different specified compressive strengths were considered for lightweight concrete, 3,000 psi (20.7 MPa), 4,000 psi (27.6 MPa), and 5,000 psi (34.5 MPa);
- **Water to cementitious materials ratio** (w/cm) – Varies, but lower for higher strength concrete mixtures in accordance with ACI 211.1;
- **SCM reactivity** – assumes 75% reactivity for fly ash (FA) as compared to portland cement and 100% reactivity of slag cement (SL) as compared to portland cement based on NRMCA member feedback;
- **Admixtures use** – Products (mix designs) with specified compressive strength less than or equal to 5,000 psi (34.5 MPa) included an air entraining admixture since many of these concretes would be exposed to freezing and thawing. Products (mix designs) with specified compressive strength above 5,000 psi (34.5 MPa) did not include air entraining admixture since these higher strengths concretes are rarely exposed to freezing and thawing; water reducing and accelerating admixture used across all mixes; high range water reducer admixtures were assumed to be used in high strength mix designs (5,000 psi (34.5 MPa) and above).
- **Aggregate use** – The normal weight concrete mixes contain natural and crushed coarse and fine aggregates that are of typical weight and composition. The lightweight concrete mixes substitute typical coarse aggregate with an expanded clay product that reduces the mass of aggregate for a given mix, and thus the overall mass of the lightweight mix concrete products. See Table 2: A1 Raw Material Supply.

Table 1 lists the 72 products (mix designs) considered in the LCA and EPD. They have been purposely enumerated in ranges of mix design properties to cover a significant range of possible products and to conservatively estimate life cycle impact indicators; i.e., all product life cycle impacts are calculated at the upper bound of the strength range and lower bound of the indicated SCM percentage and thus, providing a conservative estimate the life cycle impacts associated with each product. The product name is represented by the specified compressive strength and the quantity (%) of portland cement and SCMs (either fly ash or slag cement or both) used to estimate the life cycle impact indicators and resource use metrics. Appendix A lists the specific material input quantities considered for each RMC product.
## Table 1. Declared Product Range Classification

<table>
<thead>
<tr>
<th>Specified Compressive Strength Range</th>
<th>SCM Range (%)</th>
<th>Product Name</th>
</tr>
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<tbody>
<tr>
<td><strong>0-2500 psi (0-17.24 MPa)</strong></td>
<td></td>
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<tr>
<td>0-19% Fly Ash and/or Slag</td>
<td>2500-00-FA/SL</td>
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<tr>
<td>20-29% Fly Ash</td>
<td>2500-20-FA</td>
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<tr>
<td>30-39% Fly Ash</td>
<td>2500-30-FA</td>
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<tr>
<td>40-49% Fly Ash</td>
<td>2500-40-FA</td>
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<tr>
<td>30-49% Slag</td>
<td>2500-30-SL</td>
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<tr>
<td>40-49% Slag</td>
<td>2500-40-SL</td>
<td></td>
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<tr>
<td>≥50% Slag</td>
<td>2500-50-SL</td>
<td></td>
</tr>
<tr>
<td>≥20% Fly Ash and ≥30% Slag</td>
<td>2500-50-FA/SL</td>
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<td><strong>2501-3000 psi (17.25-20.68 MPa)</strong></td>
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<td>0-19% Fly Ash and/or Slag</td>
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<td>0-19% Fly Ash and/or Slag</td>
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<td>6001-8000 psi</td>
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<td>LW-3000-50-50</td>
</tr>
<tr>
<td></td>
<td>≥20% Fly Ash and ≥30% Slag</td>
<td>LW-3000-50-FA/SL</td>
</tr>
<tr>
<td>Lightweight</td>
<td>0-19% Fly Ash and/or Slag</td>
<td>LW-4000-00-FA/SL</td>
</tr>
<tr>
<td>3001-4000 psi</td>
<td>20-29% Fly Ash</td>
<td>LW-4000-20-FA</td>
</tr>
<tr>
<td></td>
<td>30-39% Fly Ash</td>
<td>LW-4000-30-FA</td>
</tr>
<tr>
<td>(20.69-27.58 MPa)</td>
<td>40-49% Fly Ash</td>
<td>LW-4000-40-FA</td>
</tr>
<tr>
<td></td>
<td>30-39% Slag</td>
<td>LW-4000-30-50</td>
</tr>
<tr>
<td></td>
<td>40-49% Slag</td>
<td>LW-4000-40-50</td>
</tr>
<tr>
<td></td>
<td>≥50% Slag</td>
<td>LW-4000-50-50</td>
</tr>
<tr>
<td></td>
<td>≥20% Fly Ash and ≥30% Slag</td>
<td>LW-4000-50-FA/SL</td>
</tr>
<tr>
<td>Lightweight</td>
<td>0-19% Fly Ash and/or Slag</td>
<td>LW-5000-00-FA/SL</td>
</tr>
<tr>
<td>4001-5000 psi</td>
<td>20-29% Fly Ash</td>
<td>LW-5000-20-FA</td>
</tr>
<tr>
<td></td>
<td>30-39% Fly Ash</td>
<td>LW-5000-30-FA</td>
</tr>
<tr>
<td>(27.59-34.47 MPa)</td>
<td>40-49% Fly Ash</td>
<td>LW-5000-40-FA</td>
</tr>
<tr>
<td></td>
<td>30-39% Slag</td>
<td>LW-5000-30-50</td>
</tr>
<tr>
<td></td>
<td>40-49% Slag</td>
<td>LW-5000-40-50</td>
</tr>
<tr>
<td></td>
<td>≥50% Slag</td>
<td>LW-5000-50-50</td>
</tr>
<tr>
<td></td>
<td>≥20% Fly Ash and ≥30% Slag</td>
<td>LW-5000-50-FA/SL</td>
</tr>
</tbody>
</table>
3.4 Cut-off Criteria

The cut-off criteria for all activity stage flows considered within the system boundary conform with ISO14044:2006 and section 3.3 of the governing PCR. Specifically, the cut-off criteria were applied as follows:

- All inputs and outputs for which data are available are included in the calculated effects and no collected core process data are excluded.
- A one percent cut-off is considered for renewable and non-renewable primary energy consumption and the total mass of inputs within a unit process. The sum of the total neglected flows does not exceed 5% of all energy consumption and mass of inputs.
- All flows known to contribute a significant impact or to uncertainty (e.g., portland cement and admixtures) are included;
- The cut-off rules are not applied to hazardous and toxic material flows – all of which are included in the life cycle flow inventory.

3.5 Exclusions from product system

Except as noted in Section 3.1, all other life cycle stages as described in Figure 1 are excluded from the LCA study and EPD (modules A4-A5 for central mix plants and the delivery portion of A4 for truck-mixing plants, B1-7, and C1-4). In conformance with the PCR, the following life cycle processes are excluded from the study:

- Production, manufacturer and construction of buildings’ capital goods and infrastructure.
- Production and manufacture of concrete production equipment, concrete delivery vehicles, earthmoving equipment, and laboratory equipment.
- Personnel-related activities (travel, furniture, office supplies)
- Energy and water use related to company management and sales activities, which may be located either within the factory site or at another location.
- Water use in the placement and curing of concrete.
- Intermediate waste flows from the production of some raw material inputs\(^4\).

---

\(^4\) All waste treatment processes within the cradle-to-gate production of raw material (A1) inputs are included within the system boundaries. For some of these materials, however, the total amount of all intermediate waste flows (i.e. totals of hazardous and non-hazardous waste) was not readily available. The intermediate waste flows for the production of cement, slag cement, and aggregate inputs were available and are included in the hazardous and non-hazardous waste totals. This means that the intermediate waste flows are included for >99% of all material inputs which falls within the cut-off criteria.
4 Life Cycle Inventory Analysis

The material and unit process data underlying this study and the resultant EPD were derived from various sources. Secondary LCI data sources were generally used to compile material and energy flows (Module A1), while primary data were collected for process inputs (A2 and A3). This section qualitatively and quantitatively describes the various data sources used to compile the life cycle inventory metrics and subsequent life cycle impact assessment (LCIA) indicator results for the 72 declared RMC product designs.

4.1 Primary Data Sources

NRMCA engaged the Athena Institute in 2013 to develop a cradle-to-gate life cycle inventory questionnaire for the manufacture of ready mixed concrete and to survey a sub-population of its members to support the development of a “representative” LCA and EPD for ready mixed concrete as produced by its members. NRMCA reengaged Athena in 2015 to build on the previous modeling by adding more plants to the sample.

At the outset of this project the goal was to develop a “representative” statistical sample of NRMCA member plants with a 95% confidence level and a 5% margin of error. Based on NRMCA’s US 2012 ready mixed concrete production data and estimated average plant production by region, a distribution of ready mix plants across NRMCA’s 8 regions was estimated. There are approximately 7,000 plants across the ready mixed concrete industry. NRMCA estimates that their membership represents 30% of all companies and 50% of all plants operating in 2012. Using a sample size calculator\(^5\) it was determined that a minimum of 350 plants would need to be “sampled” to achieve the desired confidence level and margin of error. A total of 517 data collection surveys were distributed to NRMCA members in 2013 taking into consideration regional production, plant size and type; 425 surveys were returned, of which 412 were deemed complete after conducting a completeness and mass balance check. A statistical analysis was again performed and determined that the “representativeness” goal was surpassed – achieving a 95% confidence level with a 4.24% margin of error.

In version 2, we requested an additional 88 surveys and received 64, bringing the new totals to 605 surveys distributed and an overall sample size of 494 plants. The margin of error was recalculated for the combined sample (494 plants) and adjusted population (2557 eligible plants), and resulted in a 3.96% margin of error (confidence interval) at a 95% confidence level.

The survey questionnaire distributed with Version 2 of the study requested 2015\(^6\) annual material and resource inputs (A1), material input transportation by mode and distance (A2), annual RMC production and manufacturing process input flows – energy use by type, ancillary inputs, process emissions to air, water and land (A3) and in the event the plant was a truck-mixing plant, its delivery vehicle fleet energy use (A4). A detailed statistical study\(^7\) completed for NRMCA indicates that the mixing energy (power take off) represents about 30.2% of all fuel inputs.

---

\(^5\) Sample size calculator – www.surveysystem.com

\(^6\) Version 1 of the study surveyed 2013 annual production

used by a concrete mixing truck. This value is applied for the truck-mixing portion of the sample and is reflected in the LCI model (A3) for this project.

All LCI data were collected using US Customary units (lbs, tons, cubic yard) and horizontally averaged on a per cubic yard basis (inputs/outputs divided by total production) prior to conversion to SI units (cubic meter) basis. In instances where plant data were missing for a particular parameter of interest, that plant’s data was removed from the horizontal averaging for that parameter. The overall loss rate (returned and disposed of concrete) for the industry sample was calculated at 0.5%.

The LCI data collection questionnaire is publically available from NRMCA. The resulting statistical summary report “NRMCA V2 LCI Data Collection Summary Statistics, August 2016” (and supplementary data analysis) is confidential, but has been made available to NSF International to expedite the review of these primary data and this LCA project report. Appendix B summarizes the material input, transportation and core process technosphere flows as modeled in the underlying LCA model.

4.2 Secondary Data Sources
All upstream material, resource and energy carrier inputs have been sourced from various industry-average datasets and literature. Many of these data sets are defaulted to those specified for use in the CLF PCR, v1.1 (2013). Care was taken to fill known data gaps (dummies) as recorded in the US LCI database profiles.

Tables 2 to 4 describe each LCI data source for raw materials (A1), transportation by mode (A2) and the RMC core manufacture process (A3 and A4) as well as an assessment of data quality.

<table>
<thead>
<tr>
<th>Table 2. A1 - Raw Material Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials</strong></td>
</tr>
</tbody>
</table>
| Cement (lbs) | Portland Cement Association EPD USA Portland Cement, 2016 | USA | 2014 | • Technology: good  
Process models USA industry average portland cement production  
• Time: good  
Data is within 2 years  
• Geography: very good  
• Completeness: good  
• Reliability: very good, third-party verified EPD |
| Fly Ash (lbs) | None, no incoming burden, only inbound transport was considered | N/A | N/A | N/A  
Recovered material |
| Silica Fume (lbs) | None, no incoming burden, only inbound transport was considered | N/A | N/A | N/A  
Recovered material |
<table>
<thead>
<tr>
<th>Materials</th>
<th>LCI Data Source</th>
<th>Geography</th>
<th>Year</th>
<th>Data Quality Assessment</th>
</tr>
</thead>
</table>
| Slag Cement (lbs)                 | Slag Cement Association N. America EPD Slag Cement, 2015 | N. America    | 2013-2014 | • **Technology:** good  
Process models ground granulated blast furnace slag  
• **Time:** good  
Data is within 3 years  
• **Geography:** very good  
• **Completeness** good  
• **Reliability:** very good, third-party verified EPD |
| Crushed Aggregates (lbs) coarse and fine | ecoinvent process: “Gravel, crushed, at mine”  
ecoinvent 2.02 | EU            | 2004       | • **Technology:** good  
Processes represent aggregate, with and without crushing. Dust emissions are estimated from limestone mining.  
• **Time:** fair  
Data is twelve years old but technology remains consistent across the industry  
• **Geography:** fair  
Processes model Swiss production (no US process in USLCI database).  
• **Completeness:** very good  
• **Reliability:** very good  
Data is verified by ecoinvent. |
| Natural Aggregates (lbs) coarse and fine | CLF PCR Default  
ecoinvent process: “Gravel, round, at mine”,  
ecoinvent 2.02 | EU            | 2004       | • **Technology:** good  
Processes represent aggregate, with and without crushing. Dust emissions are estimated from limestone mining.  
• **Time:** fair  
Data is twelve years old but technology remains consistent across the industry  
• **Geography:** fair  
Processes model Swiss production (no US process in USLCI database).  
• **Completeness:** very good  
• **Reliability:** very good  
Data is verified by ecoinvent. |
| Manufactured Lightweight Aggregates (lbs) | ecoinvent, Expanded clay  
USA | 2013 | | • **Technology:** good  
Process represents production of manufactured lightweight aggregate used in the production of lightweight concrete. Based on the following generic process description, http://www.epa.gov/ttnchie1/ap42/ch11/final/c11s20.pdf. Most lightweight aggregate is produced from materials such as clay, shale, or slate.  
• **Time:** good  
Data is within 3 years.  
• **Geography:** good  
Processes model US production.  
• **Completeness:** very good  
• **Reliability:** very good  
Data is verified by ecoinvent. |
| Admixtures (lbs)                   | EFCA  
EcoProfiles (300, 301, 302, 303, 324 and 325) | EU            | 2005 - 2006 | • **Technology:** very good  
Processes represents admixture production for use in concrete  
• **Time:** fair  
Data is within eleven years  
• **Geography:** fair  
• **Completeness:** good  
Data from a federation of European admixture producers  
• **Reliability:** good  
Profiles have undergone an independent review process. Compliance with ISO standards (unknown) |
<table>
<thead>
<tr>
<th>Materials</th>
<th>LCI Data Source</th>
<th>Geography</th>
<th>Year</th>
<th>Data Quality Assessment</th>
</tr>
</thead>
</table>
| Concrete Batch and Wash Water (gallons) | Primary | USA | 2013 & 2015 | *Technology*: very good  
Data represents fresh batch water, recycled wash water used as batch water and wash water inputs  
*Time*: very good  
Data is within three years  
*Geography*: very good  
*Completeness*: very good  
Primary data from core processes survey  
*Reliability*: very good  
Data based on specified use |
| Crushed Returned Concrete (lbs) | Primary (Pre-consumer, burden of crushing is reported and included in module A3) | USA | 2013 & 2015 | *Technology*: very good  
Primary data collected via industry survey  
*Time*: very good  
Data is within three years  
*Geography*: very good  
*Completeness*: very good  
Primary data from core processes survey  
*Reliability*: very good  
Data based on specified use |
| Crushed Demolition Concrete (lbs) | LCI Slag Cement Manufacturing (crushing data used as proxy) | USA | 2003 | *Technology*: good  
Process models crushing of blast furnace slag.  
*Time*: fair  
Data is within thirteen years.  
*Geography*: very good  
*Completeness*: fair  
*Reliability*: fair |
| Road Dust Control Chemicals (lbs) | ecoinvent 3.01, Calcium chloride used to control dust on gravel roadways CaCl2, 35-38 wt. percent calcium chloride solution to the roadway | Europe | 2008 | *Technology*: good  
Process models the manufacture of dust control chemical.  
*Time*: fair  
Data is within ten years.  
*Geography*: fair  
Processes model Swiss production  
*Completeness*: very good  
*Reliability*: very good  
Data is verified by ecoinvent. |
| Oil, Lubricants and Greases (lbs) | ecoinvent 3.01, Lubricating oil (US) | US | 2008 | *Technology*: good  
Process models the manufacture of lubricants  
*Time*: fair  
Data is within ten years.  
*Geography*: good  
Processes model US production  
*Completeness*: very good  
*Reliability*: very good  
Data is verified by ecoinvent. |
### Table 2. A1 - Raw Material Supply

<table>
<thead>
<tr>
<th>Materials</th>
<th>LCI Data Source</th>
<th>Geography</th>
<th>Year</th>
<th>Data Quality Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning Chemicals (lbs)</td>
<td>ecoinvent 3.01, 50% &quot;RustAway&quot; modeled as 0.844 lb/gal of &quot;Phosphoric acid, industrial grade, without water, in 85% solution state {GLO}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>market for</td>
<td>Alloc Def, U* and ecoinvent 3.01, 50% &quot;FoamAway&quot; modeled as 0.4 lb/gal of &quot;Citric acid {GLO}</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>market for</td>
<td>Alloc Def, U</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Global</td>
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<td></td>
<td></td>
<td>2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• <strong>Technology:</strong> good</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Processes model the manufacture of primary cleaning active ingredients</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Time:</strong> fair</td>
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<tr>
<td></td>
<td></td>
<td>Data is within ten years.</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Geography:</strong> fair</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Global process model</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• <strong>Completeness:</strong> very good</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• <strong>Reliability:</strong> very good</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Data is verified by ecoinvent.</td>
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</tr>
</tbody>
</table>

* Rail, ocean, and freighter data was republished by USLCI in 2014, but only the road profile was updated. All road transportation was modeled as short distance hauls (<200 miles) which reflects the supply chain – see Appendix B for average transportation distances.

### Table 3. A2 - Transportation

<table>
<thead>
<tr>
<th>Process</th>
<th>LCI Data Source</th>
<th>Geography</th>
<th>Year</th>
<th>Data Quality Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail, ocean freighter and barge* (lbs*miles)</td>
<td>USLCI - rail transport, diesel powered; ocean freighter, average fuel mix; barge, average fuel mix</td>
<td>USA</td>
<td>2008</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• <strong>Technology:</strong> very good</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Processes represents U.S average transportation profiles</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• <strong>Time:</strong> fair</td>
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<td></td>
<td></td>
<td></td>
<td>Data is within ten years</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>• <strong>Geography:</strong> good</td>
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<td></td>
<td></td>
<td>• <strong>Completeness:</strong> good (all data place holders filled)</td>
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<td></td>
<td></td>
<td></td>
<td>Data is representative of US conditions</td>
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<td></td>
<td></td>
<td></td>
<td>• <strong>Reliability:</strong> good</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Data is from USLCI database</td>
</tr>
<tr>
<td>Road (lbs*miles)</td>
<td>USLCI 2014 – single unit truck transport, diesel powered, short haul US avg.;</td>
<td>USA</td>
<td>2014</td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>• <strong>Technology:</strong> very good</td>
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<td>Processes represents U.S average transportation profiles</td>
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<td></td>
<td>• <strong>Time:</strong> very good</td>
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<td></td>
<td></td>
<td>Data is within two years</td>
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<td></td>
<td></td>
<td></td>
<td>• <strong>Geography:</strong> good</td>
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<td>• <strong>Completeness:</strong> good (all data place holders filled)</td>
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<td>Data is representative of US conditions</td>
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<td></td>
<td>• <strong>Reliability:</strong> good</td>
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<td></td>
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<td>Data is from USLCI database</td>
</tr>
</tbody>
</table>
### Table 4. A3 - Manufacturing

<table>
<thead>
<tr>
<th>Process</th>
<th>LCI Data Source</th>
<th>Geography</th>
<th>Year</th>
<th>Data Quality Assessment</th>
</tr>
</thead>
</table>
| Electricity (kWh)               | NRMCA purchased electricity grid mix- Electricity, medium voltage, at grid, US (ecoinvent v3.01) | US        | 2008/2013 | • **Technology**: very good  
Process represents production of electricity in the appropriate NERC regions. An average NRMCA electricity grid was developed based on total purchased electricity by surveyed plants weighted by RMC production in various NERC regions. (See % contribution by NERC grid region below)  
• **Time**: fair/good  
Electricity production data is within ten years. NERC regional production breakdown from 2013.  
• **Geography**: very good  
• **Completeness**: good  
Data is representative of US production  
• **Reliability**: good  
ecoinvent has verified the data |
| Natural Gas (cu.ft.)            | USLCI, Natural gas, combusted in industrial boiler/US                           | US        | 2008      | • **Technology**: very good  
Process represents combustion of natural gas in an industrial boiler.  
• **Time**: fair  
Data is within ten years  
• **Geography**: fair  
• **Completeness**: good  
Data is representative of US conditions  
• **Reliability**: good  
Data is from USLCI database |
| Fuel Oil (other than diesel), (gallon) | US LCI: Residual fuel oil, combusted in industrial boiler/US                   | US        | 2008      | • **Technology**: very good  
Process represents combustion of RFO in an industrial boiler.  
• **Time**: fair  
Data is within ten years  
• **Geography**: fair  
• **Completeness**: good  
Data is representative of US conditions  
• **Reliability**: good  
Data is from USLCI database |
<table>
<thead>
<tr>
<th>Process</th>
<th>LCI Data Source</th>
<th>Geography</th>
<th>Year</th>
<th>Data Quality Assessment</th>
</tr>
</thead>
</table>
| Diesel (gallon)                                  | US LCI: Diesel, combusted in industrial equipment/US | US        | 2008 | - **Technology**: very good  
|                                                  |                                                      |           |      | Process represents combustion of diesel in industrial equipment.  
|                                                  |                                                      |           |      | - **Time**: fair  
|                                                  |                                                      |           |      | Data is within ten years  
|                                                  |                                                      |           |      | - **Geography**: fair  
|                                                  |                                                      |           |      | - **Completeness**: good  
|                                                  |                                                      |           |      | Data is representative of US conditions  
|                                                  |                                                      |           |      | - **Reliability**: good  
|                                                  |                                                      |           |      | Data is from USLCI database  |
| Gasoline (gallon)                                | US LCI: Gasoline, combusted in equipment/US          | US        | 2008 | - **Technology**: very good  
|                                                  |                                                      |           |      | Process represents combustion of gasoline in equipment.  
|                                                  |                                                      |           |      | - **Time**: fair  
|                                                  |                                                      |           |      | Data is within ten years  
|                                                  |                                                      |           |      | - **Geography**: fair  
|                                                  |                                                      |           |      | - **Completeness**: good  
|                                                  |                                                      |           |      | Data is representative of US conditions  
|                                                  |                                                      |           |      | - **Reliability**: good  
|                                                  |                                                      |           |      | - Data is from USLCI database  |
| Liquefied Propane Gas (gallon)                   | US LCI: Liquefied petroleum gas, combusted in industrial boiler/US | US        | 2008 | - **Technology**: very good  
|                                                  |                                                      |           |      | Process represents combustion of LPG in industrial boiler.  
|                                                  |                                                      |           |      | - **Time**: fair  
|                                                  |                                                      |           |      | Data is within ten years  
|                                                  |                                                      |           |      | - **Geography**: fair  
|                                                  |                                                      |           |      | - **Completeness**: good  
|                                                  |                                                      |           |      | Data is representative of US conditions  
|                                                  |                                                      |           |      | - **Reliability**: good  
|                                                  |                                                      |           |      | - Data is from USLCI database  |
| Secondary Fuels, Liquid (waste solvents, etc.), (lbs) | ecoinvent 3.1, 2014 -Spent solvent mixture (US)| EU        | 2008 | - **Technology**: good  
|                                                  | treatment of, hazardous waste incineration |           |      | combustion emissions only  
|                                                  | Alloc Def, U -Combustion emissions are only included |           |      | - **Time**: fair  
|                                                  |                                                      |           |      | Data is within ten years.  
|                                                  |                                                      |           |      | - **Geography**: fair  
|                                                  |                                                      |           |      | Processes model Swiss production (no US process in USLCI database).  
|                                                  |                                                      |           |      | - **Completeness**: very good  
|                                                  |                                                      |           |      | - **Reliability**: very good  
|                                                  |                                                      |           |      | Data is verified by Ecoinvent.  |
| Secondary Fuels, Solid (tires, etc.), (ton-short) | ecoinvent 3.01: Waste rubber, unspecified (US) | EU        | 2008 | - **Technology**: good  
|                                                  | treatment of, municipal incineration |           |      | combustion emissions only  
|                                                  | Alloc Def, U |                                                      |      | - **Time**: fair  
|                                                  |                                                      |           |      | Data is within ten years.  
|                                                  |                                                      |           |      | - **Geography**: fair  
|                                                  |                                                      |           |      | Processes model Swiss production (no US process in USLCI database).  
|                                                  |                                                      |           |      | - **Completeness**: very good  
|                                                  |                                                      |           |      | - **Reliability**: very good  
|                                                  |                                                      |           |      | Data is verified by Ecoinvent.  |
### Table 4. A3 - Manufacturing

<table>
<thead>
<tr>
<th>Process</th>
<th>LCI Data Source</th>
<th>Geography</th>
<th>Year</th>
<th>Data Quality Assessment</th>
</tr>
</thead>
</table>
| Hazardous Solid Waste, (lbs) | ecoinvent 3.1, 2014 - Hazardous waste, for incineration (US) | EU | 2008 | - Technology: good  
- Time: fair  
  Data is within ten years.  
- Geography: fair  
  Processes model Swiss production (no US process in USLCI database).  
- Completeness: very good  
- Reliability: very good  
  Data is verified by Ecoinvent. |
- Time: fair  
  Data is within ten years.  
- Geography: fair  
  Processes model Swiss production (no US process in USLCI database).  
- Completeness: very good  
- Reliability: very good  
  Data is verified by Ecoinvent. |

<table>
<thead>
<tr>
<th>NRMCA Purchased Electricity source grid mix (as modeled)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity, medium voltage (FRCC) market for Alloc Def, U</td>
<td>6.35%</td>
</tr>
<tr>
<td>Electricity, medium voltage (MRO) market for Alloc Def, U</td>
<td>6.29%</td>
</tr>
<tr>
<td>Electricity, medium voltage (NPCC) market for Alloc Def, U</td>
<td>4.15%</td>
</tr>
<tr>
<td>Electricity, medium voltage (RFC) market for Alloc Def, U</td>
<td>12.95%</td>
</tr>
<tr>
<td>Electricity, medium voltage (SERC) market for Alloc Def, U</td>
<td>34.10%</td>
</tr>
<tr>
<td>Electricity, medium voltage (SPP) market for Alloc Def, U</td>
<td>2.96%</td>
</tr>
<tr>
<td>Electricity, medium voltage (TRE) market for Alloc Def, U</td>
<td>7.79%</td>
</tr>
<tr>
<td>Electricity, medium voltage (WECC) market for Alloc Def, U</td>
<td>25.41%</td>
</tr>
<tr>
<td>Total</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

### 4.3 Calculation Method

For purposes of calculating the requisite resource metrics and life cycle impact indicators (see Section 5 below), LCI datasets are created for each energy/fuel type as well as raw material (lb) and transportation mode (lb-miles), as specified by the RMC product mix design, in SimaPro (modules A1 and A2). With respect to purchased electricity, an average NRMCA electricity grid was developed based on the surveyed plants weighted by RMC production in the various NERC regions. (see % contribution by NERC grid region Table 4 above).

Similarly, a weighted-average manufacturing process LCI per cubic yard of concrete (module A3) is also created in SimaPro which reflects the weighted average mix of plant types and sizes as developed via the NRMCA plant survey. For each information module, the set of metrics and indicators are generated and exported to a project specific EPD calculator tool, where they are combined with the material quantities for the 72 RMC product mix designs to generate the total cradle-to-gate life cycle indicators and resource use metrics on a cubic yard basis. These
results are then converted to a cubic meter basis for compliance reporting purposes as per the CLF PCR.

4.4 Allocation

As prescribed by the CLF PCR, the applied allocation procedures conform with ISO14044 clause 4.3.4. In most cases RMC is the only product produced at NRMCA facilities; however, for instances where co-products were encountered LCI flows were allocated on a mass basis across the RMC and the co-product of concern. For truck-mixing plants a portion (30.2%) of the reported fleet energy use was allocated to the mixing facility based on a previous power take-off study conducted on behalf of the NRMCA (see section 4.1 above).

4.5 Data Quality

Data quality requirements, as specified in the CLF PCR: 2013, sections 3.5 and 3.6, are applied and reported in Tables 2 to 4. This section also describes the achieved data quality relative to the ISO 14044:2006 requirements. This LCA and resulting EPD was created using industry average data for upstream materials. Data variation can result from differences in supplier locations, manufacturing processes, manufacturing efficiency and fuel types used. Data quality is judged on the basis of its representativeness (technological, temporal, and geographical), completeness (e.g., unreported emissions), consistency and reliability.

All LCI data (Tables 2 to 4) are assessed on the basis of the five data quality indicators listed below. Each indicator is interpreted with respect to its context and key determining data parameters are discussed to provide clarity as to how the overall quality of each indicator is assessed and stated.

- **Technical representativeness:** The degree to which the data reflects the actual technology(ies) used. Core manufacturing process technology is derived from very recent annual data covering a large number of plant sizes and types. These data are deemed to be reflective of typical or average technologies used within the US and Canada in the production of ready-mixed concrete. Some background material and process data are European but deemed to be similar to technologies used in the US and Canada and are often cited as preferred “default data” in the governing CLF PCR.

  **Overall quality - Good to very good**

- **Temporal representativeness:** The degree to which the data reflects the actual time (e.g. year) or age of the activity. Core manufacturing process data is very recent (2013 and 2015). All significant LCI data sources, those that exercise a large influence over the calculated results, are generally less than 10 years old.

  **Overall quality - Fair to very good**

- **Geographical representativeness:** The degree to which the data reflects the actual geographic location of the activity (e.g. country or site). Geographical coverage of core manufacturing processes is specific to the US and Canada. All energy profiles reflect US and Canadian conditions. Some material (aggregates and admixtures) and process data are based on European sources. These data have been previously verified or listed in the governing PCR for default use.

  **Overall quality - Fair to very good**
Completeness: The degree to which the data are statistically representative of the relevant activity. Completeness includes the percentage of locations for which data is available and used out of the total number that relate to a specific activity. Core manufacturing processes are very complete and were derived from a statistical sample with a 95% confidence interval and less than 5% error. These data reflect annual operations inclusive of seasonal and other normal annual fluctuations in operations. All relevant, specific processes, including inputs (raw materials, energy and ancillary materials) and outputs (emissions and production volume) were considered and modeled to represent the specified and declared RMC products. The relevant background materials and processes were taken from the US LCI Database (adjusted for known data placeholders); US system boundary adjusted ecoinvent v 2.2 and v3.0 LCI databases and modeled in SimaPro software v8.1.1. Efforts were made to ensure that all data used was as complete as reasonably possible.

Overall quality - Good to very good

Reliability: The degree to which the sources, data collection methods and verification procedures used to obtain the data are dependable. For core manufacturing processes the reliability of the information and data is deemed to be very good as these were derived from a large, statistically significant, survey of ready-mixed concrete producers and subsequently reviewed by the NRMCA for plausability. Similarly, the LCI data for portland cement, at plant, reflects a very recent EPD. All missing process data (dummies) associated with the US LCI data have been consistently filled. All other LCI data have been incorporated in accordance with the default PCR requirements or derived from ecoinvent databases, which have been verified by ecoinvent.

Overall quality - Fair to very good

Furthermore, the data quality is evaluated on the basis the precision, consistency and reproducibility.

Precision: The NRMCA participating member companies through measurement and calculation collected primary data on their annual production of RMC products. For accuracy the LCA team validated these plant gate-to-gate input and output data. A statistical analysis was completed and documented in a separate report – see Primary Data Sources section.

Consistency: To ensure consistency, the LCI modeling of the production weighted input and output LCI data for the declared products used the same modeling structure across the respective product systems, which consisted of input raw and ancillary material, energy flows, water resource inputs, product and co-products outputs, returned and recovered concrete materials, emissions to air, water and soil, and waste recycling and treatment. The same background LCI datasets from the NRMCA SimaPro LCI database were used across all RMC product systems LCI modeling. Crosschecks concerning the plausibility of mass and energy flows were continuously conducted. The LCA team conducted mass and energy balances at the plant and selected process level to maintain a high level of consistency.

Reproducibility: Internal reproducibility is possible since the data and the models are stored and available in a database (NRMCA SimaPro LCI database, 2016). A considerable level of transparency is provided throughout the report as the specifications and material quantity make-up for the declared RMC products are presented and key primary and secondary LCI data sources
are summarized in Tables 2, 3 and 4. The provision of more detailed data to allow full external reproducibility was not possible due to reasons of confidentiality.

5 Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) is the phase in which the set of results of the inventory analysis – the inventory flow table – is further processed and interpreted in terms of environmental impacts\(^8\) and resource use inventory metrics. As specified in the CLF PCR:2013, Section 8., the US EPA Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), version 2.1, 2012 impact categories shall be used as they provide a North American context for the mandatory category indicators to be included in the EPD. Additionally, the PCR requires a set of inventory metrics to be reported with the LCIA indicators (see Table 5).

This section presents the inventory metrics and life cycle impact indicator results for the 72 RMC product design mixes. These results are a function of LCI modeling and life cycle assessment as performed using SimaPro v8.1.1 with the LCI data sets as described in Section 4 of this report.

<table>
<thead>
<tr>
<th>#</th>
<th>LCIA Indicators</th>
<th>Abbreviations</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Global Warming Potential (climate change)</td>
<td>GWP</td>
<td>kg CO2-eq</td>
</tr>
<tr>
<td>2</td>
<td>Ozone Depletion Potential</td>
<td>ODP</td>
<td>kg CFC-11-eq</td>
</tr>
<tr>
<td>3</td>
<td>Acidification Potential</td>
<td>AP</td>
<td>kg SO2-eq</td>
</tr>
<tr>
<td>4</td>
<td>Eutrophication Potential</td>
<td>EP</td>
<td>kg N-eq</td>
</tr>
<tr>
<td>5</td>
<td>Photochemical Ozone Creation/Smog Potential</td>
<td>POCP</td>
<td>kg O3-eq</td>
</tr>
<tr>
<td>6</td>
<td>Total primary energy consumption</td>
<td>PEC</td>
<td>MJ (HHV)</td>
</tr>
<tr>
<td>7</td>
<td>Depletion of non-renewable energy resources</td>
<td>NRE</td>
<td>MJ (HHV)</td>
</tr>
<tr>
<td>8</td>
<td>Use of renewable primary energy</td>
<td>RE</td>
<td>MJ (HHV)</td>
</tr>
<tr>
<td>9</td>
<td>Depletion of non-renewable material resources</td>
<td>NRM</td>
<td>kg</td>
</tr>
<tr>
<td>10</td>
<td>Use of renewable material resources</td>
<td>RM</td>
<td>kg</td>
</tr>
<tr>
<td>11</td>
<td>Concrete batching water consumption</td>
<td>CBW</td>
<td>m3</td>
</tr>
<tr>
<td>12</td>
<td>Concrete washing water consumption</td>
<td>CWW</td>
<td>m3</td>
</tr>
<tr>
<td>13</td>
<td>Total water consumption</td>
<td>TW</td>
<td>m3</td>
</tr>
<tr>
<td>14</td>
<td>Concrete hazardous waste</td>
<td>CHW</td>
<td>kg</td>
</tr>
<tr>
<td>15</td>
<td>Concrete non-hazardous waste</td>
<td>CNHW</td>
<td>kg</td>
</tr>
</tbody>
</table>

HHV – higher heating value - is equal to the lower heating value with the addition of the heat of vaporization of the water content in the fuel.

\(^8\)Category indicators present possible or potential impacts and are based on environmental impacts that may be realized if the emitted chemical compound(s) actually follows the designated impact pathway and reacts accordingly in the receiving environment. Each potential impact pathway is calculated in isolation, and while a number of compounds may contribute to two or more pathways, no effort is made to partition individual chemical compound flows between impact pathways. As a result, LCIA results are only relative expressions of potentials and do not predict actual impacts, the exceeding of thresholds, safety margins or risks.
A short description of TRACI 2.1 impact categories (IC) and characterization factors (CF) is provided below. A characterization factor is a factor derived from a characterization model, which is applied to convert an assigned life cycle inventory analysis result to the common unit for the category indicator. The common unit allows calculation of the category indicator result.

- **Global warming (IC)** – TRACI calculates global warming potential (GWP), a midpoint CF metric proposed by the International Panel on Climate Change (IPCC), for the calculation of the potency of greenhouse gases relative to carbon dioxide (CO₂). The 100-year time horizons recommended by the IPCC and used by the US for policy making and reporting are adopted within TRACI. The methodology and science behind the global warming potential calculation is considered one of the most accepted LCIA categories. Within TRACI 2.1, the most current GWPs published by IPCC (2013) were used for each substance. GWP_{100} is expressed on equivalency basis relative to CO₂, that is, equivalent CO₂ mass basis.

- **Ozone depletion (IC)** – Stratospheric ozone depletion (ODP) is the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substances. International consensus exists on the use of ozone depletion potentials-ODPs (CF), a metric proposed by the World Meteorological Organization (WMO) for calculating the relative importance of chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HFCs), and halons expected to contribute significantly to the breakdown of the ozone layer. Within TRACI 2.1, the most recent sources of ODPs (WMO 2003) were used for each substance, where chemicals are characterized relative to trichlorofluoromethane (CFC-11).

- **Acidification (IC)** – According to TRACI 2.1, acidification (AP) comprises processes that increase the acidity (hydrogen ion concentration, [H+]) within a local environment. This can be the result of the addition of acids (e.g., nitric acid and sulfuric acid) into the environment, or by the addition of other substances (e.g., ammonia) which increase the acidity of the environment due to various chemical reactions and/or biological activity, or by natural circumstances such as the change in soil concentrations because of the growth of local plant species [7]. Acidification is a more regional rather than global impact affecting water and soil. Consistent with the focus on providing midpoint assessments, TRACI 2.1 uses an acidification model which incorporates the increasing hydrogen ion potential within the environment without incorporation of site-specific characteristics such as the ability for certain environments to provide buffering capability. Acidification is expressed in kg SO₂ equivalent.

- **Eutrophication (IC)** – In TRACI 2.1, eutrophication (EP) is defined as the fertilization of surface waters by nutrients that were previously scarce. This measure encompasses the release of mineral salts and their nutrient enrichment effects on waters – typically made up of nitrogen (N) and phosphorous (P) compounds and organic matter flowing into waterways. The result is expressed on an equivalent mass of nitrogen basis. The characterization factors estimate the eutrophication potential of a release of chemicals containing N or P to air or water, per kilogram of chemical released, relative to 1 kg N discharged directly to surface freshwater.
- **Photochemical ozone creation/smog (IC)** – Photochemical ozone formation potential (CF)
  - Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NOx). The “smog” (POCP) indicator is expressed on a mass of equivalent ozone (O$_3$) basis.

### 5.1 Life Cycle Impact Assessment Results

The following Tables 6 to 14 summarize the LCA results for each of the eight product mix designs considered within each compressive strength class on cubic meter of ready-mixed product basis. All product life cycle results are calculated at the upper bound of the strength class and lower bound of the indicated SCM percentage to conservatively estimate the life cycle impacts. Each table also reports the minimum and maximum indicator/inventory metric result within each compressive strength range. A second Table 6a to 14a reports the same results on a cubic yard of product basis.

This LCA does not cover any “additional environmental information” as specified in the CLF PCR, clause 3.2.
### Table 6. Summary Results (A1-A3): 0-2500 psi (0-17.24 MPa) RMC product, per cubic meter

<table>
<thead>
<tr>
<th>Indicator/LCI Metric</th>
<th>GWP</th>
<th>ODP</th>
<th>AP</th>
<th>EP</th>
<th>POPC</th>
<th>PEC</th>
<th>NRE</th>
<th>RE</th>
<th>NRM</th>
<th>RM</th>
<th>CBW</th>
<th>CWW</th>
<th>TW</th>
<th>CHW</th>
<th>CNHW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit (equivalent)</td>
<td>kg CO2</td>
<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
<td>MJ</td>
<td>MJ</td>
<td>MJ</td>
<td>kg</td>
<td>kg</td>
<td>m3</td>
<td>m3</td>
<td>m3</td>
<td>kg</td>
<td>kg</td>
</tr>
<tr>
<td>Minimum</td>
<td>185.7</td>
<td>5.4E-06</td>
<td>0.78</td>
<td>0.24</td>
<td>16.57</td>
<td>1,490.7</td>
<td>1,462.5</td>
<td>26.52</td>
<td>2,044.6</td>
<td>1.49</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
<td>0.42</td>
<td>3.82</td>
</tr>
<tr>
<td>Maximum</td>
<td>300.6</td>
<td>7.6E-06</td>
<td>1.01</td>
<td>0.36</td>
<td>20.92</td>
<td>1,993.5</td>
<td>1,956.1</td>
<td>37.40</td>
<td>2,264.8</td>
<td>2.22</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
<td>0.45</td>
<td>4.96</td>
</tr>
<tr>
<td>2500-00-FA/SL</td>
<td>300.6</td>
<td>7.6E-06</td>
<td>1.01</td>
<td>0.36</td>
<td>20.92</td>
<td>1,993.5</td>
<td>1,956.1</td>
<td>37.40</td>
<td>2,264.8</td>
<td>2.22</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
<td>0.45</td>
<td>4.96</td>
</tr>
<tr>
<td>2500-20-FA</td>
<td>258.5</td>
<td>6.5E-06</td>
<td>0.90</td>
<td>0.31</td>
<td>18.86</td>
<td>1,758.4</td>
<td>1,726.1</td>
<td>32.25</td>
<td>2,163.8</td>
<td>1.91</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
<td>0.42</td>
<td>4.60</td>
</tr>
<tr>
<td>2500-30-FA</td>
<td>235.7</td>
<td>6.0E-06</td>
<td>0.84</td>
<td>0.29</td>
<td>17.74</td>
<td>1,631.8</td>
<td>1,602.3</td>
<td>29.46</td>
<td>2,109.1</td>
<td>1.74</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
<td>0.42</td>
<td>4.40</td>
</tr>
<tr>
<td>2500-40-FA</td>
<td>211.7</td>
<td>5.4E-06</td>
<td>0.78</td>
<td>0.26</td>
<td>16.57</td>
<td>1,499.0</td>
<td>1,472.5</td>
<td>26.52</td>
<td>2,051.5</td>
<td>1.56</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
<td>0.42</td>
<td>4.20</td>
</tr>
<tr>
<td>2500-30-3-L</td>
<td>231.6</td>
<td>6.9E-06</td>
<td>0.96</td>
<td>0.29</td>
<td>18.92</td>
<td>1,737.5</td>
<td>1,704.0</td>
<td>33.49</td>
<td>2,151.6</td>
<td>1.82</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
<td>0.44</td>
<td>4.27</td>
</tr>
<tr>
<td>2500-40-3-L</td>
<td>208.7</td>
<td>6.7E-06</td>
<td>0.95</td>
<td>0.27</td>
<td>18.26</td>
<td>1,653.4</td>
<td>1,621.2</td>
<td>32.19</td>
<td>2,113.8</td>
<td>1.69</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
<td>0.45</td>
<td>4.05</td>
</tr>
<tr>
<td>2500-50-3-L</td>
<td>185.7</td>
<td>6.4E-06</td>
<td>0.93</td>
<td>0.24</td>
<td>17.60</td>
<td>1,568.4</td>
<td>1,537.5</td>
<td>30.89</td>
<td>2,076.1</td>
<td>1.56</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
<td>0.45</td>
<td>3.82</td>
</tr>
<tr>
<td>2500-50-FA/SL</td>
<td>186.0</td>
<td>5.8E-06</td>
<td>0.85</td>
<td>0.24</td>
<td>16.76</td>
<td>1,490.7</td>
<td>1,462.5</td>
<td>28.13</td>
<td>2,044.6</td>
<td>1.49</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
<td>0.44</td>
<td>3.88</td>
</tr>
</tbody>
</table>

### Table 6a. Summary Results (A1-A3): 0-2500 psi (0-17.24 MPa) RMC product, per cubic yard

<table>
<thead>
<tr>
<th>Indicator/LCI Metric</th>
<th>GWP</th>
<th>ODP</th>
<th>AP</th>
<th>EP</th>
<th>POPC</th>
<th>PEC</th>
<th>NRE</th>
<th>RE</th>
<th>NRM</th>
<th>RM</th>
<th>CBW</th>
<th>CWW</th>
<th>TW</th>
<th>CHW</th>
<th>CNHW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit (equivalent)</td>
<td>kg CO2</td>
<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
<td>MJ</td>
<td>MJ</td>
<td>MJ</td>
<td>MJ</td>
<td>kg</td>
<td>kg</td>
<td>m3</td>
<td>m3</td>
<td>m3</td>
<td>kg</td>
</tr>
<tr>
<td>Minimum</td>
<td>142.0</td>
<td>4.1E-06</td>
<td>0.60</td>
<td>0.18</td>
<td>12.67</td>
<td>1,139.7</td>
<td>1,118.2</td>
<td>20.28</td>
<td>1,563.2</td>
<td>1.14</td>
<td>0.10</td>
<td>0.09</td>
<td>0.22</td>
<td>0.32</td>
<td>2.92</td>
</tr>
<tr>
<td>Maximum</td>
<td>229.8</td>
<td>5.8E-06</td>
<td>0.77</td>
<td>0.28</td>
<td>15.99</td>
<td>1,524.2</td>
<td>1,495.6</td>
<td>28.59</td>
<td>1,731.6</td>
<td>1.69</td>
<td>0.10</td>
<td>0.09</td>
<td>0.22</td>
<td>0.35</td>
<td>3.79</td>
</tr>
<tr>
<td>2500-00-FA/SL</td>
<td>229.8</td>
<td>5.8E-06</td>
<td>0.77</td>
<td>0.28</td>
<td>15.99</td>
<td>1,524.2</td>
<td>1,495.6</td>
<td>28.59</td>
<td>1,731.6</td>
<td>1.69</td>
<td>0.10</td>
<td>0.09</td>
<td>0.22</td>
<td>0.32</td>
<td>3.79</td>
</tr>
<tr>
<td>2500-20-FA</td>
<td>197.6</td>
<td>5.0E-06</td>
<td>0.69</td>
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<td>14.42</td>
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### Table 7. Summary Results (A1-A3): 2501-3000 psi (17.25-20.68 MPa) RMC product, per cubic meter

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<th>EP</th>
<th>POC</th>
<th>PEC</th>
<th>NRE</th>
<th>RE</th>
<th>NRM</th>
<th>RM</th>
<th>CBW</th>
<th>CWW</th>
<th>TW</th>
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<th>CNHW</th>
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<tbody>
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<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
<td>MJ</td>
<td>MJ</td>
<td>MJ</td>
<td>kg</td>
<td>kg</td>
<td>m3</td>
<td>m3</td>
<td>kg</td>
<td>kg</td>
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<td>0.26</td>
<td>17.81</td>
<td>1,621.4</td>
<td>1,590.2</td>
<td>29.35</td>
<td>2,034.3</td>
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<td>0.12</td>
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<tr>
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<td>2,283.8</td>
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<td>0.26</td>
<td>18.03</td>
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### Table 7a. Summary Results (A1-A3): 2501-3000 psi (17.25-20.68 MPa) RMC product, per cubic yard

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<th>AP</th>
<th>EP</th>
<th>POC</th>
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<th>RE</th>
<th>NRM</th>
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<th>CBW</th>
<th>CWW</th>
<th>TW</th>
<th>CHW</th>
<th>CNHW</th>
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<tbody>
<tr>
<td>Unit (equivalent)</td>
<td>kg CO2</td>
<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
<td>MJ</td>
<td>MJ</td>
<td>MJ</td>
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<tr>
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<td>1,555.3</td>
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### Table 8. Summary Results (A1-A3): 3001-4000 psi (20.69-27.58 MPa) RMC product, per cubic meter

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<th>EP</th>
<th>POC</th>
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<th>CWW</th>
<th>TW</th>
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<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
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### Table 8a. Summary Results (A1-A3): 3001-4000 psi (20.69-27.58 MPa) RMC product, per cubic yard

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<th>EP</th>
<th>POC</th>
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<th>CNHW</th>
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<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
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<td>kg</td>
<td>kg</td>
<td>m3</td>
<td>m3</td>
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<td>1,779.1</td>
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<td>1.54</td>
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### Table 9. Summary Results (A1-A3): 4001-5000 psi (27.59-34.47 MPa) RMC product, per cubic meter

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<th>AP</th>
<th>EP</th>
<th>POCB</th>
<th>PEC</th>
<th>NRE</th>
<th>RE</th>
<th>NRM</th>
<th>RM</th>
<th>CBW</th>
<th>CWW</th>
<th>TW</th>
<th>CHW</th>
<th>CNHW</th>
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<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
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<td></td>
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<tr>
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<td>2,221.9</td>
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<td>1,983.0</td>
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<td>0.12</td>
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<td>0.43</td>
<td>4.72</td>
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<td>3,110.0</td>
<td>62.64</td>
<td>2,377.1</td>
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<td>3,172.6</td>
<td>3,110.0</td>
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<td>2,377.1</td>
<td>3.73</td>
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<td>2,196.3</td>
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<td>0.12</td>
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<td>4.72</td>
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### Table 9a. Summary Results (A1-A3): 4001-5000 psi (27.59-34.47 MPa) RMC product, per cubic yard

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<th>Indicator/LCI Metric Unit (equivalent)</th>
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<th>ODP</th>
<th>AP</th>
<th>EP</th>
<th>POCB</th>
<th>PEC</th>
<th>NRE</th>
<th>RE</th>
<th>NRM</th>
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<th>CWW</th>
<th>TW</th>
<th>CHW</th>
<th>CNHW</th>
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<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
<td>MJ</td>
<td>MJ</td>
<td>MJ</td>
<td>kg</td>
<td>kg</td>
<td>m3</td>
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<td>0.29</td>
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<td>1,516.1</td>
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<td>0.33</td>
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Table 10. Summary Results (A1-A3): 5001-6000 psi (34.48-41.37 MPa) RMC product, per cubic meter

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<th>AP</th>
<th>EP</th>
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<th>CBW</th>
<th>CWW</th>
<th>TW</th>
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<th>CNHW</th>
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<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
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Table 10a. Summary Results (A1-A3): 5001-6000 psi (34.48-41.37 MPa) RMC product, per cubic yard

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<th>AP</th>
<th>EP</th>
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<th>PEC</th>
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<th>RE</th>
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<th>RM</th>
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<td>kg N</td>
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<td>kg</td>
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## Table 11. Summary Results (A1-A3): 6001-8000 psi (41.38-55.16 MPa) RMC product, per cubic meter

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<th>AP</th>
<th>EP</th>
<th>POCO</th>
<th>PEC</th>
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<th>RE</th>
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<td>kg O3</td>
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## Table 11a. Summary Results (A1-A3): 6001-8000 psi (41.38-55.16 MPa) RMC product, per cubic yard

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<th>AP</th>
<th>EP</th>
<th>POCO</th>
<th>PEC</th>
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<th>RE</th>
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<td>kg N</td>
<td>kg O3</td>
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### Table 12. Summary Results (A1-A3): Lightweight 2501-3000 psi (17.25-20.68 MPa) RMC product, per cubic meter

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<tr>
<th>Indicator/LCI Metric Unit (equivalent)</th>
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<th>AP</th>
<th>EP</th>
<th>POCP</th>
<th>PEC</th>
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<th>RM</th>
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<th>CWW</th>
<th>TW</th>
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<tr>
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<td>kg CO2</td>
<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
<td>MJ</td>
<td>MJ</td>
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</tr>
<tr>
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<td>0.50</td>
<td>26.28</td>
<td>3,249.2</td>
<td>3,209.7</td>
<td>39.53</td>
<td>1,713.9</td>
<td>8.20</td>
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<td>0.42</td>
<td>4.11</td>
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<td>4,366.6</td>
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<td>1,940.9</td>
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<td>0.47</td>
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<td>4,366.6</td>
<td>56.31</td>
<td>1,940.9</td>
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<td>0.13</td>
<td>0.12</td>
<td>0.58</td>
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<td>5.55</td>
</tr>
<tr>
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<td>5.09</td>
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<td>3,209.7</td>
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### Table 12a. Summary Results (A1-A3): Lightweight 2501-3000 psi (17.25-20.68 MPa) RMC product, per cubic yard

<table>
<thead>
<tr>
<th>Indicator/LCI Metric Unit (equivalent)</th>
<th>GWP</th>
<th>ODP</th>
<th>AP</th>
<th>EP</th>
<th>POCP</th>
<th>PEC</th>
<th>NRE</th>
<th>RE</th>
<th>NRM</th>
<th>RM</th>
<th>CBW</th>
<th>CWW</th>
<th>TW</th>
<th>CHW</th>
<th>CHW</th>
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</thead>
<tbody>
<tr>
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<td>kg CO2</td>
<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
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<td>kg</td>
<td>m3</td>
<td>m3</td>
<td>m3</td>
<td>kg</td>
<td>kg</td>
<td></td>
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<tr>
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<td>20.09</td>
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<td>2,454.0</td>
<td>30.22</td>
<td>1,310.3</td>
<td>6.27</td>
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<td>0.09</td>
<td>0.38</td>
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<td>3.14</td>
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<td>3,381.5</td>
<td>3,338.5</td>
<td>43.05</td>
<td>1,484.0</td>
<td>8.64</td>
<td>0.10</td>
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<tr>
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### Table 13. Summary Results (A1-A3): Lightweight 3001-4000 psi (20.69-27.58 MPa) RMC product, per cubic meter

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<th>Indicator/LCI Metric</th>
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<th>AP</th>
<th>EP</th>
<th>POCP</th>
<th>PEC</th>
<th>NRE</th>
<th>RE</th>
<th>NRM</th>
<th>RM</th>
<th>CBW</th>
<th>CWW</th>
<th>TW</th>
<th>CHW</th>
<th>CNHW</th>
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<td>Unit (equivalent)</td>
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<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
<td>MJ</td>
<td>MJ</td>
<td>MJ</td>
<td>kg</td>
<td>m3</td>
<td>m3</td>
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<tr>
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<td>3,558.2</td>
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<td>1,678.1</td>
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<td>0.12</td>
<td>0.54</td>
<td>0.46</td>
<td>4.59</td>
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</table>

### Table 13a. Summary Results (A1-A3): Lightweight 3001-4000 psi (20.69-27.58 MPa) RMC product, per cubic yard

<table>
<thead>
<tr>
<th>Indicator/LCI Metric</th>
<th>GWP</th>
<th>ODP</th>
<th>AP</th>
<th>EP</th>
<th>POCP</th>
<th>PEC</th>
<th>NRE</th>
<th>RE</th>
<th>NRM</th>
<th>RM</th>
<th>CBW</th>
<th>CWW</th>
<th>TW</th>
<th>CHW</th>
<th>CNHW</th>
</tr>
</thead>
<tbody>
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<td>Unit (equivalent)</td>
<td>kg CO2</td>
<td>kg CFC-11</td>
<td>kg SO2</td>
<td>kg N</td>
<td>kg O3</td>
<td>MJ</td>
<td>MJ</td>
<td>MJ</td>
<td>kg</td>
<td>m3</td>
<td>m3</td>
<td>m3</td>
<td>kg</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>325.1</td>
<td>1.3E-05</td>
<td>1.43</td>
<td>0.44</td>
<td>22.56</td>
<td>2,756.2</td>
<td>2,720.4</td>
<td>35.74</td>
<td>1,283.0</td>
<td>6.66</td>
<td>0.10</td>
<td>0.09</td>
<td>0.38</td>
<td>0.32</td>
<td>3.44</td>
</tr>
<tr>
<td>Maximum</td>
<td>484.5</td>
<td>1.9E-05</td>
<td>1.94</td>
<td>0.62</td>
<td>29.93</td>
<td>3,797.7</td>
<td>3,746.3</td>
<td>51.45</td>
<td>1,515.4</td>
<td>9.27</td>
<td>0.10</td>
<td>0.09</td>
<td>0.45</td>
<td>0.37</td>
<td>4.83</td>
</tr>
<tr>
<td>LW-4000-00-FA/SL</td>
<td>484.5</td>
<td>1.9E-05</td>
<td>1.94</td>
<td>0.62</td>
<td>29.93</td>
<td>3,797.7</td>
<td>3,746.3</td>
<td>51.45</td>
<td>1,515.4</td>
<td>9.27</td>
<td>0.10</td>
<td>0.09</td>
<td>0.45</td>
<td>0.33</td>
<td>4.83</td>
</tr>
<tr>
<td>LW-4000-20-FA</td>
<td>416.4</td>
<td>1.6E-05</td>
<td>1.70</td>
<td>0.53</td>
<td>26.46</td>
<td>3,309.6</td>
<td>3,265.6</td>
<td>44.04</td>
<td>1,422.9</td>
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<td>0.42</td>
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</tr>
<tr>
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<td>0.48</td>
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<td>3,020.5</td>
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<td>1,376.7</td>
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<td>0.09</td>
<td>0.40</td>
<td>0.33</td>
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</tr>
<tr>
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<td>339.8</td>
<td>1.3E-05</td>
<td>1.43</td>
<td>0.44</td>
<td>22.56</td>
<td>2,756.2</td>
<td>2,720.4</td>
<td>35.74</td>
<td>1,321.8</td>
<td>6.66</td>
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<td>0.09</td>
<td>0.38</td>
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<td>27.34</td>
<td>3,450.3</td>
<td>3,403.8</td>
<td>46.50</td>
<td>1,382.8</td>
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<td>0.09</td>
<td>0.45</td>
<td>0.35</td>
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<tr>
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<td>0.50</td>
<td>26.53</td>
<td>3,345.7</td>
<td>3,300.8</td>
<td>44.92</td>
<td>1,336.8</td>
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<td>0.10</td>
<td>0.09</td>
<td>0.45</td>
<td>0.36</td>
<td>3.71</td>
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<tr>
<td>LW-4000-50-SL</td>
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<td>1.7E-05</td>
<td>1.81</td>
<td>0.46</td>
<td>25.56</td>
<td>3,207.6</td>
<td>3,164.4</td>
<td>43.14</td>
<td>1,296.0</td>
<td>8.19</td>
<td>0.10</td>
<td>0.09</td>
<td>0.44</td>
<td>0.37</td>
<td>3.44</td>
</tr>
<tr>
<td>LW-4000-50-FA/SL</td>
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<td>1.5E-05</td>
<td>1.63</td>
<td>0.44</td>
<td>23.75</td>
<td>2,945.7</td>
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<td>0.09</td>
<td>0.42</td>
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<td>3.51</td>
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</table>
### Table 14. Summary Results (A1-A3): Lightweight 4001-5000 psi (27.59-34.47 MPa) RMC product, per cubic meter

<table>
<thead>
<tr>
<th>Indicator/LCI Metric Unit (equivalent)</th>
<th>GWP</th>
<th>ODP</th>
<th>AP</th>
<th>EP</th>
<th>POC</th>
<th>PEC</th>
<th>NRE</th>
<th>RE</th>
<th>NRM</th>
<th>RM</th>
<th>CBW</th>
<th>CWW</th>
<th>TW</th>
<th>CHW</th>
<th>CNHW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>465.9</td>
<td>1.9E-05</td>
<td>2.01</td>
<td>0.62</td>
<td>31.92</td>
<td>3,883.3</td>
<td>3,831.4</td>
<td>51.86</td>
<td>1,674.9</td>
<td>9.19</td>
<td>0.13</td>
<td>0.12</td>
<td>0.51</td>
<td>0.43</td>
<td>4.76</td>
</tr>
<tr>
<td>Maximum</td>
<td>709.7</td>
<td>2.7E-05</td>
<td>2.79</td>
<td>0.91</td>
<td>43.18</td>
<td>5,490.7</td>
<td>5,415.0</td>
<td>75.63</td>
<td>2,012.7</td>
<td>13.29</td>
<td>0.13</td>
<td>0.12</td>
<td>0.61</td>
<td>0.49</td>
<td>6.83</td>
</tr>
<tr>
<td>LW-5000-00-FA/SL</td>
<td>709.7</td>
<td>2.7E-05</td>
<td>2.79</td>
<td>0.91</td>
<td>43.18</td>
<td>5,490.7</td>
<td>5,415.0</td>
<td>75.63</td>
<td>2,012.7</td>
<td>13.29</td>
<td>0.13</td>
<td>0.12</td>
<td>0.61</td>
<td>0.49</td>
<td>6.83</td>
</tr>
<tr>
<td>LW-5000-20-FA</td>
<td>605.5</td>
<td>2.3E-05</td>
<td>2.42</td>
<td>0.77</td>
<td>37.86</td>
<td>4,732.7</td>
<td>4,686.3</td>
<td>64.39</td>
<td>1,878.5</td>
<td>11.36</td>
<td>0.13</td>
<td>0.12</td>
<td>0.56</td>
<td>0.43</td>
<td>6.18</td>
</tr>
<tr>
<td>LW-5000-30-FA</td>
<td>545.8</td>
<td>2.1E-05</td>
<td>2.20</td>
<td>0.70</td>
<td>34.79</td>
<td>4,281.6</td>
<td>4,223.6</td>
<td>58.08</td>
<td>1,812.3</td>
<td>10.15</td>
<td>0.13</td>
<td>0.12</td>
<td>0.53</td>
<td>0.43</td>
<td>5.82</td>
</tr>
<tr>
<td>LW-5000-40-FA</td>
<td>489.2</td>
<td>1.9E-05</td>
<td>2.01</td>
<td>0.63</td>
<td>31.92</td>
<td>3,883.3</td>
<td>3,831.4</td>
<td>51.86</td>
<td>1,730.6</td>
<td>9.19</td>
<td>0.13</td>
<td>0.12</td>
<td>0.51</td>
<td>0.43</td>
<td>5.45</td>
</tr>
<tr>
<td>LW-5000-30-FA</td>
<td>574.9</td>
<td>2.5E-05</td>
<td>2.65</td>
<td>0.76</td>
<td>39.02</td>
<td>4,911.8</td>
<td>4,843.9</td>
<td>67.90</td>
<td>1,823.2</td>
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<td>0.12</td>
<td>0.60</td>
<td>0.47</td>
<td>5.59</td>
</tr>
<tr>
<td>LW-5000-40-FA</td>
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<td>2.63</td>
<td>0.71</td>
<td>37.81</td>
<td>4,755.3</td>
<td>4,689.7</td>
<td>65.53</td>
<td>1,754.6</td>
<td>11.89</td>
<td>0.13</td>
<td>0.12</td>
<td>0.60</td>
<td>0.48</td>
<td>5.17</td>
</tr>
<tr>
<td>LW-5000-50-FL</td>
<td>485.6</td>
<td>2.4E-05</td>
<td>2.56</td>
<td>0.66</td>
<td>36.28</td>
<td>4,533.1</td>
<td>4,470.3</td>
<td>62.79</td>
<td>1,695.8</td>
<td>11.37</td>
<td>0.13</td>
<td>0.12</td>
<td>0.59</td>
<td>0.49</td>
<td>4.76</td>
</tr>
<tr>
<td>LW-5000-50-FA/SL</td>
<td>465.9</td>
<td>2.1E-05</td>
<td>2.29</td>
<td>0.62</td>
<td>33.62</td>
<td>4,151.0</td>
<td>4,094.6</td>
<td>56.41</td>
<td>1,674.9</td>
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<td>0.12</td>
<td>0.55</td>
<td>0.47</td>
<td>4.86</td>
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### Table 14a. Summary Results (A1-A3): Lightweight 4001-5000 psi (27.59-34.47 MPa) RMC product, per cubic yard

<table>
<thead>
<tr>
<th>Indicator/LCI Metric Unit (equivalent)</th>
<th>GWP</th>
<th>ODP</th>
<th>AP</th>
<th>EP</th>
<th>POC</th>
<th>PEC</th>
<th>NRE</th>
<th>RE</th>
<th>NRM</th>
<th>RM</th>
<th>CBW</th>
<th>CWW</th>
<th>TW</th>
<th>CHW</th>
<th>CNHW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>356.2</td>
<td>1.4E-05</td>
<td>1.54</td>
<td>0.48</td>
<td>24.40</td>
<td>2,969.0</td>
<td>2,929.3</td>
<td>39.65</td>
<td>1,280.6</td>
<td>7.02</td>
<td>0.10</td>
<td>0.09</td>
<td>0.39</td>
<td>0.33</td>
<td>3.64</td>
</tr>
<tr>
<td>Maximum</td>
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<td>2.14</td>
<td>0.69</td>
<td>33.01</td>
<td>4,197.9</td>
<td>4,140.1</td>
<td>57.82</td>
<td>1,538.8</td>
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<td>0.10</td>
<td>0.09</td>
<td>0.47</td>
<td>0.38</td>
<td>5.22</td>
</tr>
<tr>
<td>LW-5000-00-FA/SL</td>
<td>542.6</td>
<td>2.1E-05</td>
<td>2.14</td>
<td>0.69</td>
<td>33.01</td>
<td>4,197.9</td>
<td>4,140.1</td>
<td>57.82</td>
<td>1,538.8</td>
<td>10.16</td>
<td>0.10</td>
<td>0.09</td>
<td>0.47</td>
<td>0.33</td>
<td>5.22</td>
</tr>
<tr>
<td>LW-5000-20-FA</td>
<td>463.0</td>
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<td>1.85</td>
<td>0.59</td>
<td>28.95</td>
<td>3,618.4</td>
<td>3,569.2</td>
<td>49.23</td>
<td>1,436.2</td>
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<td>0.09</td>
<td>0.43</td>
<td>0.33</td>
<td>4.72</td>
</tr>
<tr>
<td>LW-5000-30-FA</td>
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<td>1.6E-05</td>
<td>1.68</td>
<td>0.53</td>
<td>26.60</td>
<td>3,273.5</td>
<td>3,229.1</td>
<td>44.41</td>
<td>1,385.6</td>
<td>7.76</td>
<td>0.10</td>
<td>0.09</td>
<td>0.40</td>
<td>0.33</td>
<td>4.45</td>
</tr>
<tr>
<td>LW-5000-40-FA</td>
<td>374.0</td>
<td>1.4E-05</td>
<td>1.54</td>
<td>0.48</td>
<td>24.40</td>
<td>2,969.0</td>
<td>2,929.3</td>
<td>39.65</td>
<td>1,323.1</td>
<td>7.02</td>
<td>0.10</td>
<td>0.09</td>
<td>0.39</td>
<td>0.33</td>
<td>4.16</td>
</tr>
<tr>
<td>LW-5000-30-FL</td>
<td>439.5</td>
<td>1.9E-05</td>
<td>2.03</td>
<td>0.58</td>
<td>29.83</td>
<td>3,755.3</td>
<td>3,703.4</td>
<td>51.91</td>
<td>1,394.0</td>
<td>9.27</td>
<td>0.10</td>
<td>0.09</td>
<td>0.46</td>
<td>0.36</td>
<td>4.27</td>
</tr>
<tr>
<td>LW-5000-40-FL</td>
<td>407.5</td>
<td>1.9E-05</td>
<td>2.01</td>
<td>0.55</td>
<td>28.91</td>
<td>3,635.7</td>
<td>3,585.6</td>
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<td>1,341.5</td>
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<td>0.09</td>
<td>0.46</td>
<td>0.37</td>
<td>3.95</td>
</tr>
<tr>
<td>LW-5000-50-FL</td>
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<td>1.8E-05</td>
<td>1.96</td>
<td>0.51</td>
<td>27.74</td>
<td>3,465.8</td>
<td>3,417.8</td>
<td>48.00</td>
<td>1,296.6</td>
<td>8.70</td>
<td>0.10</td>
<td>0.09</td>
<td>0.45</td>
<td>0.38</td>
<td>3.64</td>
</tr>
<tr>
<td>LW-5000-50-FA/SL</td>
<td>356.2</td>
<td>1.6E-05</td>
<td>1.75</td>
<td>0.48</td>
<td>25.70</td>
<td>3,173.7</td>
<td>3,130.5</td>
<td>43.13</td>
<td>1,280.6</td>
<td>7.83</td>
<td>0.10</td>
<td>0.09</td>
<td>0.42</td>
<td>0.36</td>
<td>3.72</td>
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</tbody>
</table>
6 Interpretation

Contribution analysis is an analytical method used to support the interpretation of LCA results and to facilitate the comprehension and the reader's understanding of the environmental profile of the declared products.

Table 15 summarizes the results of a cradle-to-gate percent contribution analysis (for the minimum and maximum product mix design) for each compressive strength class by information module. The Table shows the percent contribution of the raw materials production (A1), transportation (A2) and RMC manufacturing core processes (A3) for the global warming potential (GWP) impact indicator and total primary energy consumption (PEC) inventory metric. Overall, upstream materials production (A1) accounts for the largest proportion of the GWP (84% to 94%) and primary energy consumption (75% to 90%) associated with the production of ready-mixed concrete. Materials transportation (A2) contributes the next highest proportion of GWP (3% to 6%) and PEC (6% to 11%) with RMC manufacturing (A3) accounting for the remaining and smallest portion of the overall GWP and energy consumption across all compressive strengths.

As one moves from the minimum to the maximum impact mix design in a compressive strength class, it is evident that upstream materials production account for a larger share of the GWP impact and consumed energy. This is due to the fact that the highest impact mix design is the 100% portland cement mix design as the manufacture of portland cement has the highest GWP and energy consumption of any of the material inputs used in the production of ready-mixed concrete.

<table>
<thead>
<tr>
<th>Specified Compressive Strength</th>
<th>Minimum &amp; Maximum</th>
<th>Global Warming Potential (GWP) - percent contribution by module</th>
<th>Total Primary Energy Consumption (PEC) - percent contribution by module</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A1</td>
<td>A2</td>
</tr>
<tr>
<td>2500 psi 17.2 MPa</td>
<td>Min.</td>
<td>87.1%</td>
<td>6.6%</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>91.6%</td>
<td>4.6%</td>
</tr>
<tr>
<td>3000 psi 20.7 MPa</td>
<td>Min.</td>
<td>88.2%</td>
<td>6.1%</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>92.3%</td>
<td>4.2%</td>
</tr>
<tr>
<td>4000 psi 27.6 MPa</td>
<td>Min.</td>
<td>90.1%</td>
<td>5.3%</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>93.5%</td>
<td>3.7%</td>
</tr>
<tr>
<td>5000 psi 34.5 MPa</td>
<td>Min.</td>
<td>91.5%</td>
<td>4.7%</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>94.4%</td>
<td>3.3%</td>
</tr>
<tr>
<td>6000 psi 41.4 MPa</td>
<td>Min.</td>
<td>91.8%</td>
<td>4.6%</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>94.6%</td>
<td>3.2%</td>
</tr>
<tr>
<td>8000 psi 55.1 MPa</td>
<td>Min.</td>
<td>92.7%</td>
<td>4.2%</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>95.2%</td>
<td>3.0%</td>
</tr>
</tbody>
</table>
6.1 Study Limitations

This study does not report all of the environmental impacts due to manufacturing of RMC. During the LCI data collection stage a number of RMC manufacturers reported other emissions (e.g., particulate matter) that are not reflected in the impact indicators or inventory metrics as prescribed by the CLF PCR. These reported emissions might impact human and/or ecosystem health. In order to assess the local impacts of product manufacturing on human health, land use and local ecology, additional analysis is required.

This project reports the results of an industry wide ‘cradle-to-gate’ LCA of RMC in order to benchmark the manufacture of RMC only. No environmental claim regarding the superiority or equivalence of RMC relative to a competing product that performs the same function is implied. An EPD does not make any statements that the product covered by the EPD is better or worse than any other product. LCIA results are only relative expressions of potentials and do not predict actual impacts, the exceeding of thresholds, safety margins or risks.

7 References

2. Carbon Leadership Forum. (2013). “Product Category Rules (PCR) for ISO 14025 Type III Environmental Product Declarations (EPDs) of Concrete v1.1”.
6. ISO 14025: 2006 Environmental labeling and declarations - Type III environmental declarations - Principles and procedures.
11. ACI 211.1: Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
12. ACI 211.2: Standard Practice for Selecting Proportions for Structural Lightweight Concrete
15. A23.1-09/A23.2-09 (R2014) - Concrete materials and methods of concrete construction/Test methods and standard practices for concrete.
## Appendix A: Mix design specifications and raw material quantities

<table>
<thead>
<tr>
<th>Product Name</th>
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<th>Mix Proportions, lb</th>
<th>Admixture Use (oz.)</th>
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* All aggregate used in lightweight mixes was modeled as manufactured lightweight aggregate.
Appendix B: NRMCA weighted average LCI data and technosphere flows per cubic yard of product

### A. LOCATION AND PRODUCTION DATA

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### B. MATERIALS

Materials that were not reported in any surveys are greyed out

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## C. AVERAGE OPERATING ENERGY AND WATER CONSUMPTION

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<td>Diesel</td>
<td>0.39</td>
<td>gallon</td>
</tr>
<tr>
<td>12</td>
<td>Gasoline</td>
<td>0.00</td>
<td>gallon</td>
</tr>
<tr>
<td>13</td>
<td>LPG (Liquified Propane Gas)</td>
<td>0.01</td>
<td>gallon</td>
</tr>
<tr>
<td>14</td>
<td>Other</td>
<td>0.00009</td>
<td>gallon</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>Water Use</th>
<th>Amount</th>
<th>Units / yd³</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>Total Water Use</td>
<td>Approx. 49.97</td>
<td>gallons/yd³</td>
</tr>
<tr>
<td>38</td>
<td>Fresh Batch Water Use</td>
<td>Calculated with mix</td>
<td>N/A</td>
</tr>
<tr>
<td>39</td>
<td>Recycled Batch Water Use</td>
<td>3.40</td>
<td>gallons/yd³</td>
</tr>
<tr>
<td>40</td>
<td>Wash Water Use</td>
<td>23.92</td>
<td>gallons/yd³</td>
</tr>
</tbody>
</table>
### D. EMISSIONS REPORTING

<table>
<thead>
<tr>
<th>#</th>
<th>Air Emissions</th>
<th>Amount</th>
<th>Units / yd³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Particulates, PM-2.5</td>
<td>0.31454</td>
<td>ounces</td>
</tr>
<tr>
<td>2</td>
<td>Particulates, PM-10</td>
<td>0.78205</td>
<td>ounces</td>
</tr>
<tr>
<td>3</td>
<td>Particulates, total</td>
<td>1.27782</td>
<td>ounces</td>
</tr>
<tr>
<td>4</td>
<td>Lead</td>
<td>0.01435</td>
<td>ounces</td>
</tr>
<tr>
<td>5</td>
<td>Hg</td>
<td>0.00015</td>
<td>ounces</td>
</tr>
<tr>
<td>6</td>
<td>CO</td>
<td>0.02320</td>
<td>ounces</td>
</tr>
<tr>
<td>7</td>
<td>Nox</td>
<td>0.04959</td>
<td>ounces</td>
</tr>
<tr>
<td>8</td>
<td>Sox</td>
<td>0.08991</td>
<td>ounces</td>
</tr>
<tr>
<td>9</td>
<td>VOC</td>
<td>0.00133</td>
<td>ounces</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>Water Emissions</th>
<th>Amount</th>
<th>Units / yd³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Suspended Solids</td>
<td>0.09913</td>
<td>ounces</td>
</tr>
<tr>
<td>2</td>
<td>Total Dissolved Solids</td>
<td>0.21797</td>
<td>ounces</td>
</tr>
<tr>
<td>3</td>
<td>Biological Oxygen Demand (BOD)</td>
<td>0.03703</td>
<td>ounces</td>
</tr>
<tr>
<td>4</td>
<td>Chemical Oxygen Demand (COD)</td>
<td>0.07527</td>
<td>ounces</td>
</tr>
</tbody>
</table>

### E. SOLID WASTE REPORTING

<table>
<thead>
<tr>
<th>#</th>
<th>Waste Type</th>
<th>Amount</th>
<th>Units / yd³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hazardous Solid Waste</td>
<td>0.69</td>
<td>lbs</td>
</tr>
<tr>
<td>2</td>
<td>Non-Hazardous Solid Waste</td>
<td>4.50</td>
<td>lbs</td>
</tr>
</tbody>
</table>