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Submission for Verification of Eco-Efficiency Analysis Under NSF Protocol P352, Part B

Green Sense® Concrete Eco-Efficiency Analysis Final Report – January 2017

Submitted by:

BASF Corporation
Product Stewardship
100 Campus Drive, Florham Park, NJ, 07932

Prepared by:

David Green, Sustainability Specialist

Anahi Grosse-Sommer, Senior Manager Applied Sustainability

Bruce Uhlman, Manager, Applied Sustainability

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1. Final Report

1.1. Executive Summary:

The purpose of this submission is to provide a written report of the methods and findings of BASF Corporation's Green Sense® Concrete Eco-Efficiency Analysis, with the intent of having it verified under the requirements of NSF Protocol P352, Part B: Verification of Eco-Efficiency Analysis Studies.

The Green Sense® Concrete Eco-Efficiency Analysis was performed by BASF according to the methodology validated by NSF International under the requirements of Protocol P352. More information on BASF's methodology and the NSF validation can be obtained at http://www.nsf.org/info/eco_efficiency.

1.2. Content of this Guidance Document

This submission outlines the methodology, study goals, design criteria, target audience, customer benefits (CB), process alternatives, system boundaries, and scenario analysis for the Green Sense® Concrete EEA study, which will be conducted in accordance with BASF Corporation's EEA (BASF EEA) methodology. This submission will provide a discussion of the basis of the eco-analysis preparation and verification work.

As required under NSF P352 Part B, along with this document, BASF is submitting the final computerized model programmed in Microsoft® Excel. The computerized model, together with this document, will aid in the final review and ensure that the data and critical review findings have been satisfactorily addressed.

2. Introduction and Study Goals:

The specific goal defined for the Green Sense® Concrete Eco-Efficiency Analysis is to quantify the differences in life cycle environmental impacts and total life cycle costs of ready-mix, precast, or manufactured concrete products over the targeted environmental and economic life cycle phases.

Green Sense® Concrete is a mixture optimization service in which supplementary cementitious materials and non-cementitious fillers are used with BASF chemical admixtures to meet or exceed performance targets and reduce the overall environmental footprint.

The study specifically compares a reference concrete mixture to different concrete mixture designs using chosen supplementary cementitious materials (SCMs) and BASF concrete admixtures. The study is a dynamic model and therefore is capable of analyzing numerous different mixture designs. All background data remains consistent for each study completed to ensure consistency.

The major factors influencing the environmental and cost impact of the concrete mixtures are the quantity of cement in a concrete blend, transportation mode and distance to deliver material to the producer site and the costs associated with the SCMs relative to cement costs. The mixture design information and associated costs are provided by the concrete producers for each analysis. Various different powder SCMs are available in the analysis however, most mixture alternatives only use one or two of the choices. All mixtures are lab evaluated to ensure that the properties and specifications meet the design requirements.

BASF Admixtures are an integral component for delivering the properties necessary to meet the design specifications and are therefore included in the study even though the amount of admixture in a standard concrete mixture is less than 1% by mass. The admixtures provide the necessary chemistry to produce a concrete product with performance characteristics equal to or better than a concrete mixture containing in many cases higher levels of cement. The optimum Green Sense® concrete mixture design generally provides an equal or better specified product with a preferable environmental footprint based on the reduction in cement content. Different combinations of admixtures may be selected based upon the raw materials chosen and the corresponding concrete mixture requirements.

Study results will be used as the basis to guide further product development and support/promote marketing strategies for more eco-efficient concrete products. The results also provide the necessary information to allow a clear comparison between the environmental life cycle and total cost impacts and benefits of producing a Green Sense® concrete solution. It will also facilitate the clear communications of these results to key stakeholders in the construction industry who are challenged with evaluating and making strategic decisions related to the environmental and total cost trade-offs associated with the production of concrete.

3. Customer Benefit, Alternatives and System Boundaries:

The customer benefit applied to all alternatives for the base case analysis is the evaluation of the inputs required to produce 1 cubic yard/cubic meter of similar compressive strength Portland cement concrete with equal or better performance characteristics including durability (service life). This study specifically evaluates different concrete mixture configurations to a reference concrete mixture for comparative purposes. The cubic yard/cubic meter customer benefit was chosen as this is a standard unit of measure used by ready-mix concrete producers throughout the world and can be easily converted to other more specific products manufactured such as precast elements and manufactured concrete units. The overall study is a dynamic model and has the capability of evaluating an unlimited number of different mixture designs with similar design and performance characteristics however each individual analysis is limited to one reference mixture and up to five alternative mixtures. As BASF does not produce the concrete but services hundreds of different concrete producers with some having thousands of different mixture designs, a single study would not be valued in the marketplace. The dynamic nature provides producers with the opportunity to evaluate their specific mixture and choose the most eco-efficient result for their product submission. The eco-efficiency analysis is conducted only on mixtures that have similar design characteristics and have been evaluated to ensure compliance with mixture design requirements. Due to the significant number of application possibilities for concrete, the use and end of life phase are considered equal and therefore not specifically included in this analysis. The analysis can only be conducted by an approved BASF eco-efficiency practitioner and all background data remains consistent for each study. Any updates to background information (updated profiles for example) will be communicated to the customer through the BASF Sales representative in the event they are using data generated in significantly different time intervals, i.e. years.

The product alternatives compared under this EEA study are a reference concrete mixture and up to five additional mixtures using different quantities and/or types of raw materials for the mixture design. Admixtures are used to promote the necessary material reactions for developing proper concrete properties, characteristics and/or application requirements.

ISO 14040 and 14044 define in which way system boundaries of a study have to be defined. The BASF EEA methodology follows these requirements. The system boundary determines which unit processes shall be included within the LCA. The selection of the system boundary shall be consistent with the goal of the study.

The system boundaries for the analysis evaluated in this study are shown in Figure 1. The use and disposal phases were excluded from the analysis as the actual application and placement of the concrete mixtures can vary between foundations, slabs-on-grade, sidewalks, driveways, roadways, bridge decks, or structural elements for example. With the various application options, the service life/design life will vary with the application adding to the complexity of evaluating the product mixtures. Therefore, this aspect of the life cycle is considered equivalent for all analyses as the end use of the specific concrete mixture will be the same and therefore not included as part of the study. The elements included in the boundary are the major impact categories for the production of concrete including material content, cost, and transportation. Although concrete production plants differ in their equipment, processing, and energy management, these components are considered identical for the study as all analyzed mixtures will be generated from a specific plant using the same equipment and processes. This will also keep the focus on the product. Other programs and certifications are available to concrete producers for managing their operating efficiencies.

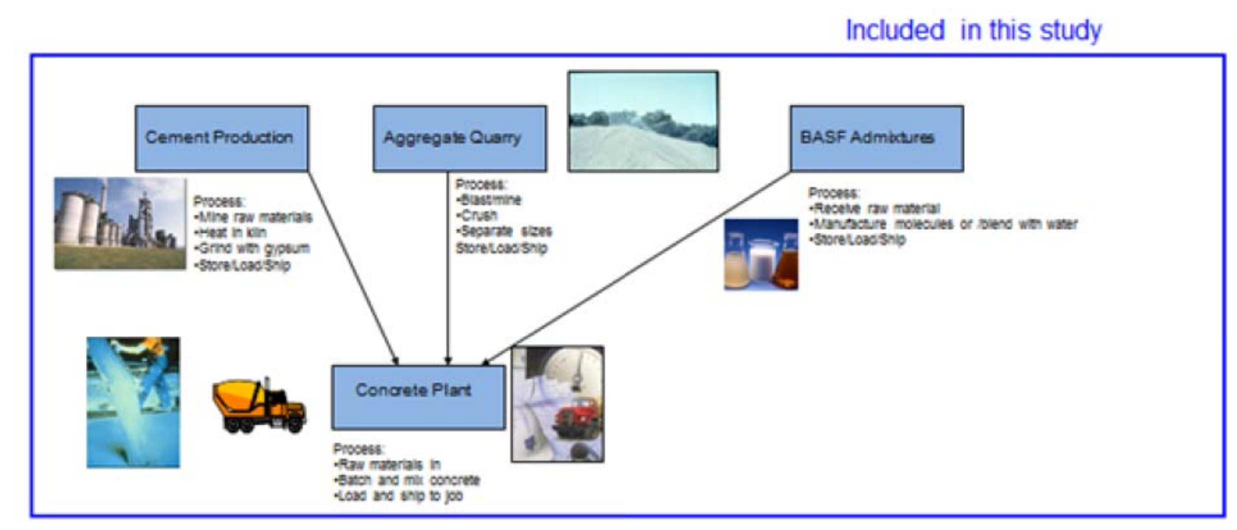


Figure 1: System boundaries – Green Sense® Concrete

4. *Input Parameters:*

A list of relevant materials used as potential inputs is included in this study although not all materials will be used in the specific study and corresponding results. The input values from this data are based on mixture design evaluations to ensure that the proper specifications and performance characteristics are achieved.

The Green Sense® concrete study evaluates the production of the Customer Benefit (CB), one cubic yard/cubic meter of similar strength concrete. Ready mix, precast and manufactured concrete products (MCP) are all comprised of cement and/or supplementary cementitious materials, fine and course aggregates, water, and generally admixtures. Additional materials may be added to concrete to improve strength (fibers) or change the aesthetic appearance (color) however all mixture designs in the analysis must then include these additions unless the design specifications and performance characteristics can be attained without the addition of these materials or products.

The input table developed for this analysis is shown in Table 1. Information for the input table is provided by each producer prior to the requested analysis. Since this is a dynamic model, each producer will have different mixtures representing their specific portfolio and therefore the input quantities will change with each analysis.

Materials			
Binders	**unit**	**Water (batch)**	**unit**
Cement	kg	Fresh water	l
Fly ash	kg	Desalinated water	l
Slag	kg	**Admixtures**	**unit**
Granite powder	kg	MasterPozzolith 322N	ml/100kg
Limestone powder	kg	MasterPozzolith 210	ml/100kg
Glass powder	kg	MasterPolyheed N	ml/100kg
Natural volcanic pozzolith	kg	MasterPolyheed 997	ml/100kg
Lime	kg	MasterRheobuild	ml/100kg
Metakaolin	kg	MasterGlenium	ml/100kg
Silica fume	kg	MasterSet AC 534	ml/100kg
Color pigments	kg	MasterSet AC 122	ml/100kg
Rice husk ash	kg	Master X-Seed	ml/100kg
Sands	**unit**	MasterSet R 300	ml/100kg
Natural sand	kg	MasterSet Delvo	ml/100kg
Natural sand, washed	kg	MasterLife 300D	kg/100kg
Manufactured sand	kg	MasterMatrix VMA 358	ml/100kg
Limestone powder	kg	MasterLife SRA 035	ml/100kg
River dredge sand	kg	MasterLife AMA 100	ml/100kg
Aggregates	**unit**	MasterAir 90	ml/100kg
Natural aggregate	kg	MasterSure Z60	ml/100kg
Recyled aggregate	kg	MasterColor	ml/100kg
Light weight aggregate	kg	MasterKure ER 50	ml/100kg
Limestone aggregate	kg	MasterLife CI 30	ml/100kg
Reinforcement Materials	**unit**		
Reinforcement - steel	kg		
Reinforcement - steel fibers	kg		
Reinforcement - macro fibers	kg		
Reinforcement - microfibres	kg		

Table 1: Material input data for Green Sense® Concrete

5. Assumptions

Transportation impacts will not have a significant impact for producers located adjacent to or in close proximity to the raw material sources including cement and the various supplementary cementitious materials but will have a more significant impact when materials are sourced from locations in different regions of the United States or from different countries.

The Use and Disposal phases for the study were considered equivalent for the purposes of the study and therefore not included in the final calculation. This assumption is based on the multitude of different applications for Green Sense® concrete including driveways, sidewalks, slabs-on-grade, bridge decks, pavers, columns, etc. which would require separate analyses for each application and include numerous additional variables for the placement and use phases. Additional analyses can be developed utilizing the Green Sense® Concrete results in combination with unique applications to develop a full life-cycle analysis based on the final structure.

6. Economic Impact Evaluation:

The exact metrics chosen for the study are dependent upon the scope of the study, the identified customer benefit, the alternatives considered and system boundaries. Economic metrics included in the BASF EEA, each of which must be consistently applied to each alternative, cover all relevant costs and may at times include revenue.

The concrete producer costs are included and evaluated for each concrete mixture design. The producer costs are based on the production of one (1) cubic yard/cubic meter of concrete as shown in Figure 2. The difference between the alternatives in the analysis are based on materials chosen for the concrete products however, all mixtures must meet the design and performance characteristics through lab testing. Costs vary from producer to producer and these costs generally are not provided to anyone other than the customer requesting the analysis for confidentiality reasons. The list of materials requiring input costs is identical to the list of input materials shown in table 1.

The primary drivers for economic differences in concrete mixtures are based on the cost of the cement replacement or supplementary cementitious materials selected for the concrete mixture.

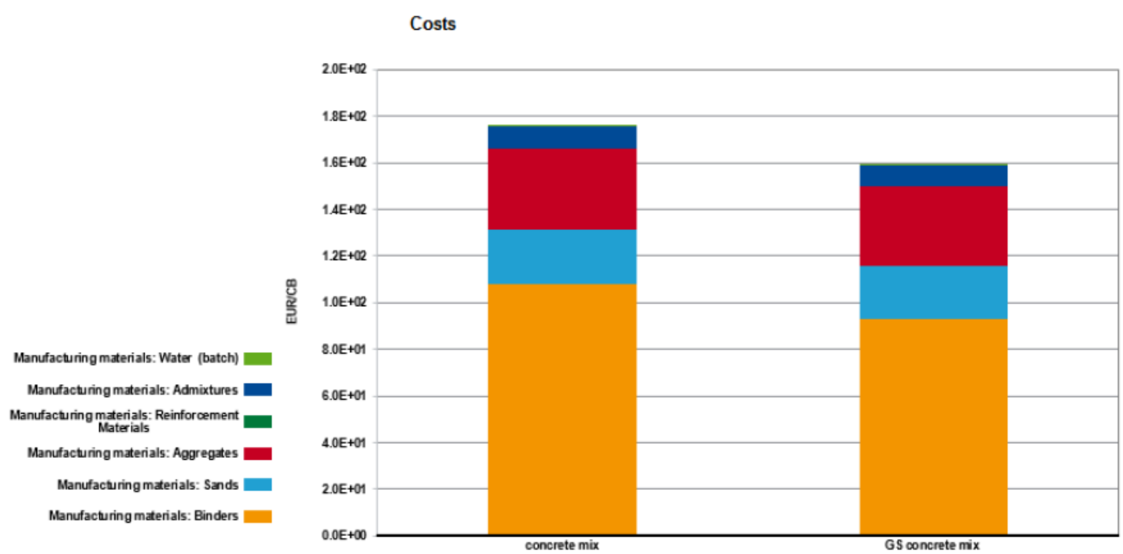


Figure 2: Economic Evaluation for Green Sense® Concrete

7. Environmental Impact Evaluation:

The LCAflex assessment was selected for the Green Sense® Concrete EEA as the selection of impact categories is flexible and may include, in addition to the EEA6 and EEA10 categories, additional categories as shown below. The selection was based on the flexibility of the studies being conducted in different regions around the world. At a minimum, the impact categories indicated by the Relevance Check will be required in the final report. The assessment methods may be chosen from standard market tools such as EU PEF, Traci 2.1, ReCiPe and CML 2002. In addition, published and accepted methodologies for specific impacts may also be applied as described in section 6.2 (for example consumptive water use according to Pfister 2009 and BASF Human Toxicity Potential [Landsiedel and Saling 2002]).

- Additional Environmental impact categories (LCAflex)
- Eutrophication (terrestrial)
- Eutrophication (overall) Respiratory inorganics Ionizing radiation
- Human toxicity potential (cancer)
- Human toxicity potential (non-cancer)
- Ecotoxicity potential (freshwater)
- Ecotoxicity potential (terrestrial)
- Ecotoxicity potential (marine)

This is an open list and can be extended (with published impact categories/methodologies) depending on the needs of the customers in different regions.

The impact categories are aggregated to a total environmental impact based on: (a) all the impacts indicated by the Relevance Check being included (b) weighting factors exist for all impact categories (c) no double counting of an impact category.

For some studies, the report may include additional categories in the LCAflex without including these in the aggregated total environmental impact.

8. Eco-Efficiency Analysis Results, Interpretation and Discussion:

The environmental impact results for an example Green Sense® concrete EEA are shown on the environmental footprint. The environmental footprint shows the environmental impact of each of the defined concrete mixtures relative to one another in all of the assessed impact categories.

The alternative that lies furthest from the origin has the value of 1.00 and is the least favorable (highest impact) alternative in the category under consideration. The closer to the origin an alternative lies (0,0 coordinate), the lower the environmental impact.

The axes coordinates are calculated independent of one another, so an alternative that, for example, does well in abiotic depletion (resource depletion – mineral, fossil) may perform worse when compared to consumptive water use (resource depletion water). A representative footprint for a Green Sense® Concrete study is depicted below in Figure 3.

In each of the environmental impact categories, the Green Sense® Concrete mixture for this analysis shows lower results in each of the independent environmental categories.

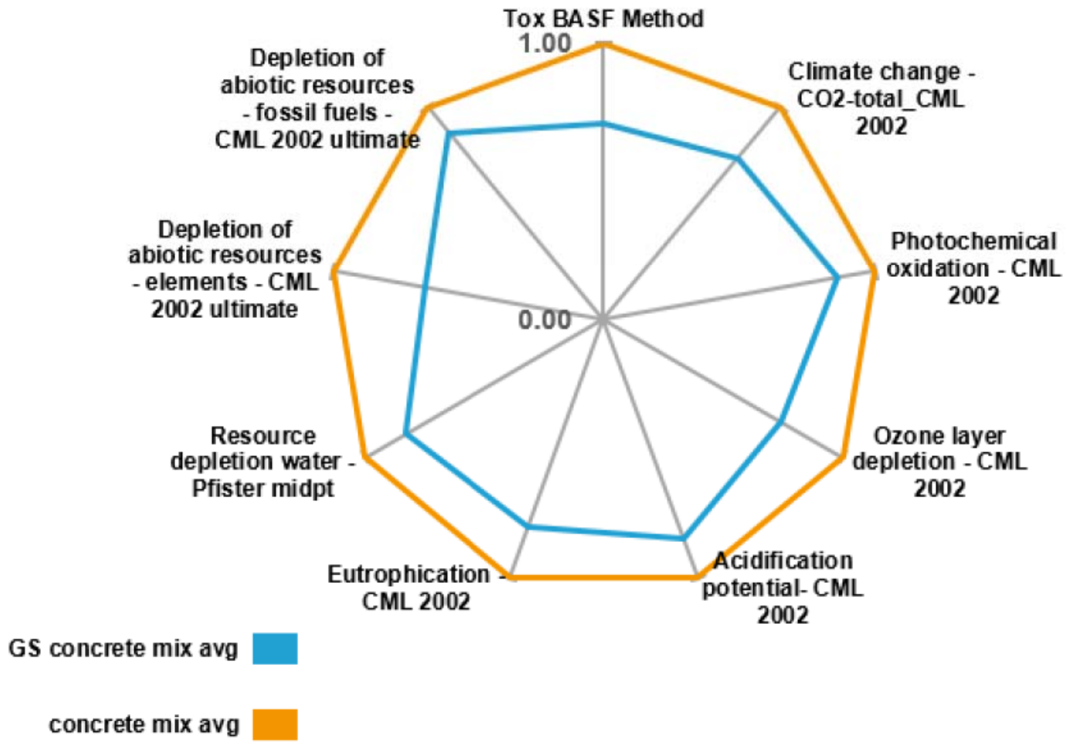


Figure 3: Alternatives in a Green Sense® Concrete Environmental Footprint

Bar charts are generated at a minimum for each of the environmental impact categories depicted by the relevance check shown in Figure 4. For the sample study in this report, the top four impact categories are Global Warming Potential (GWP), Photochemical Ozone Creation Potential (POCP), Acidification Potential (AP) and Human Toxicity overall. Each of the bar charts are shown below. The bar chart diagrams give an indication which life cycle steps, processes and product changes may be having the largest impact on the results and thus offer the greatest potential improvement opportunities.

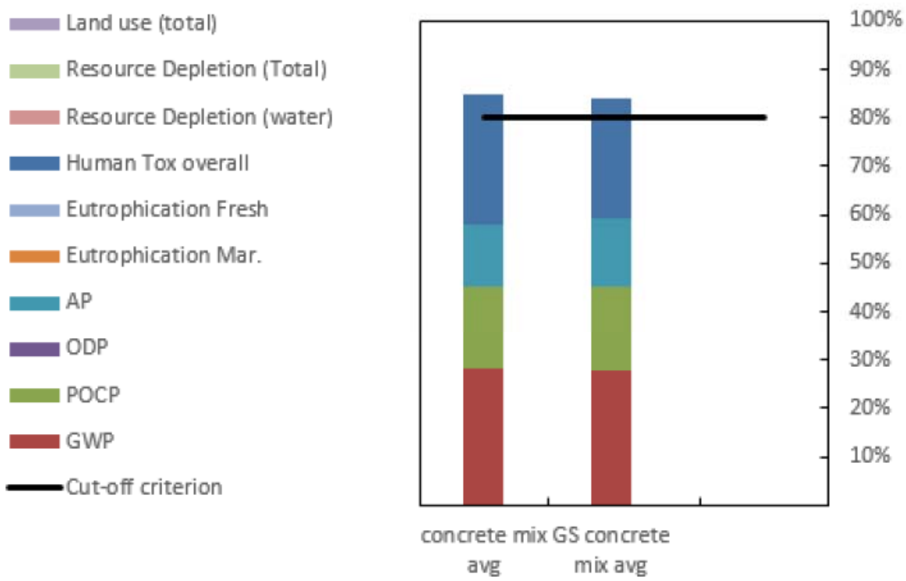
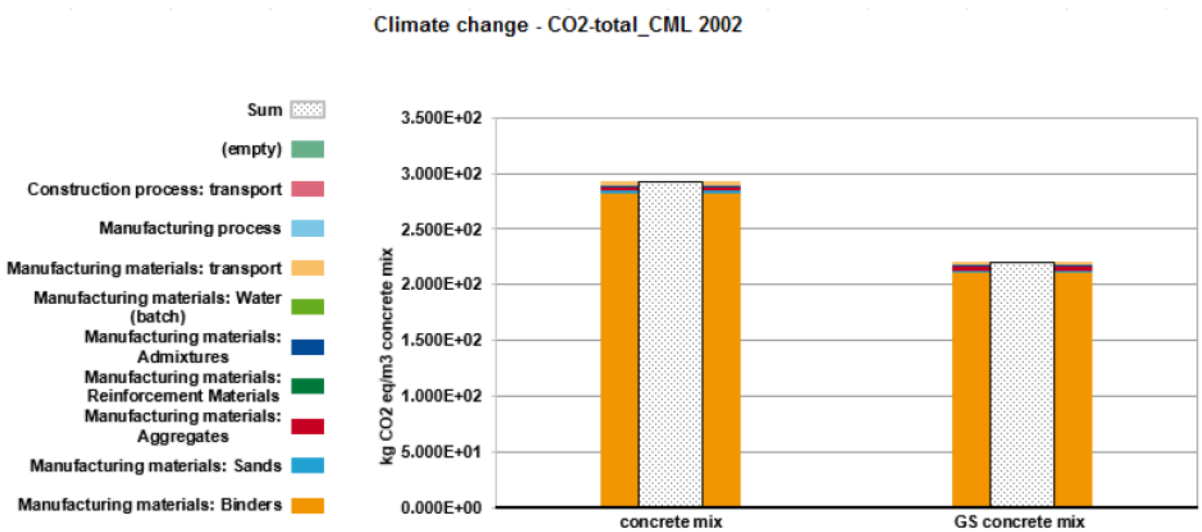


Figure 4: Relevance Check for Green Sense® Concrete example

8.1. Global Warming Potential

Also referred to as Climate Change and carbon footprint, this category reflects the climate change impact of the air emissions of greenhouse gases (GHGs). Increased GHGs in the troposphere result in warming of the earth's surface. The impact of greenhouse gas emissions, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), is assessed over a fixed time period of 100 years. The climate change category takes into account that different gases have different climate change impacts on global warming. The total impact is described in CO_2 equivalents.

The primary input driving the Climate Change results is the Manufacturing Materials: Binders. As the cement content is reduced, the overall Climate Change results are also lowered.



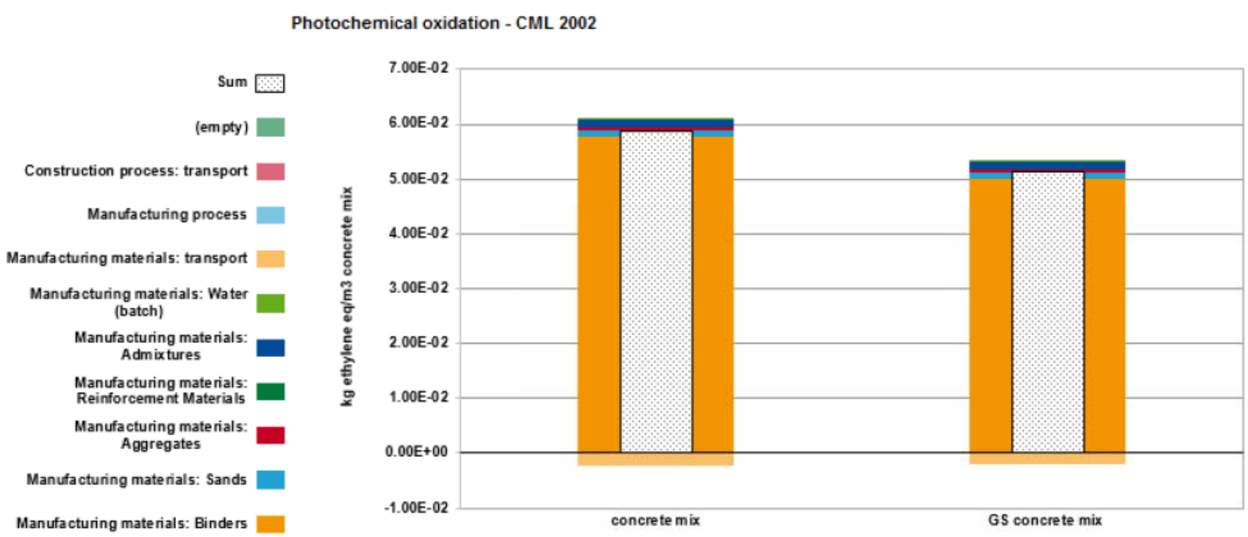
8.2. POCP - Photochemical Ozone Creation Potential

Also referred to as photochemical ozone formation and photochemical ozone creation potential (POCP). This category reflects the impact of certain air emissions on summer smog formation. Emissions of VOCs (volatile organic compounds) in the presence of nitrogen oxides (NOx) and sunlight can lead to chemical reactions that form ozone close to ground level (also called photochemical or tropospheric smog).

Ground level ozone can result in negative health effects, including eye irritation, respiratory tract and lung irritation, as well as damage to vegetation.

Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NOx and VOC.

Results are reported in kg NMVOC-equivalents (or in ethylene equivalents or O_3 equivalent dependent on the impact assessment methodology). The primary change in photochemical ozone creation potential is attributed to the change in cement mass between the concrete mixture and the Green Sense® concrete mixture.



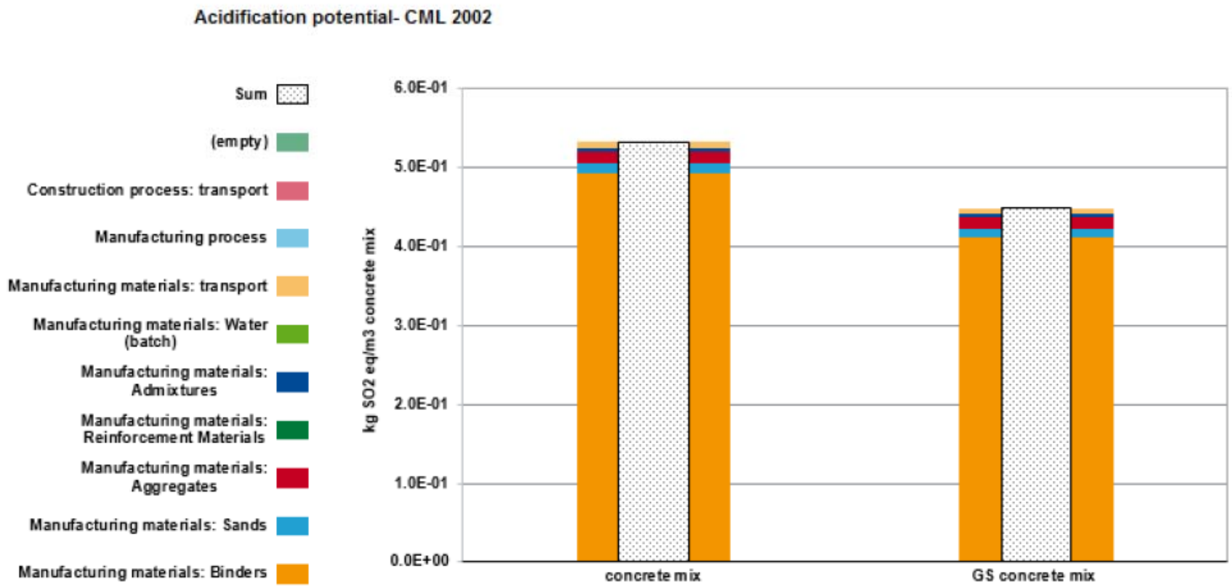
8.3. Acidification Potential

Also referred to as acidification, this category summarizes the effect of total emissions of acidic gases to air. Deposition of these emissions can acidify water bodies and soils, and can cause building corrosion.

AP-relevant gases include e.g. sulfur oxides (SOx), nitrogen oxides (NOx), hydrochloric acid (HCl) and hydrofluoric acid (HF). Typical sources of acidifying emissions are fossil fuel combustion for electricity production, heating and transport, and agriculture.

The total impact is expressed in mol H+ equivalents (or in SO_2 equivalents dependent on the impact assessment methodology)

The cement content in the two mixtures is the primary impact material generating acidification potential within the two mixtures. The reduction in cement content in the Green Sense concrete mixture lowers the overall acidification potential by almost 16%.



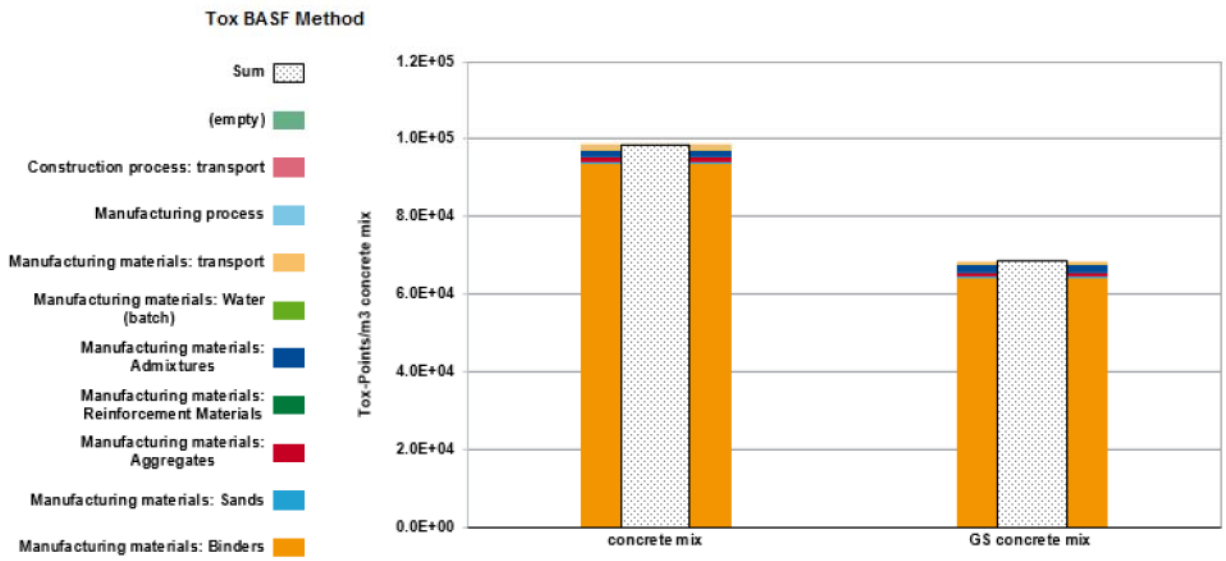
8.4. Human Toxicity

The human toxicity potential takes into consideration all substances handled at any time during the life cycle of a product. Only toxicity potentials are assessed, not actual risks. Substances are assigned toxicity points based on their hazard phrases (H-phrases) of the Globally Harmonized System (GHS). The H-phrases indicate human health hazards associated with exposure to specific substances. These toxicity points are multiplied with the amounts of substances used and report life cycle human toxicity potentials expressed in terms of dimensionless toxicity points.

The method is described in detail in R. Landsiedel, P. Saling, Int. J. LCA 7 (5), 261-268, (2002)[12]. In cooperation with toxicologists, toxicity points were assigned to each H-phrase.

The toxicity potential for the various concrete mixture alternatives was analyzed for the production phase of their respective life cycles. The use phase for the concrete can vary significantly based on the specific application of the concrete. As the mixture design has potential use in driveways, highways, foundations, slabs, decks, etc. the complexity of including the use component for this analysis was too high. Therefore, the analysis assumes that the use phase and disposal phase for each of the mixture alternatives is consistent and therefore will not impact the results of the intended analysis. For the production phase, not only were the final products considered but the entire pre-chain of chemicals required to manufacture the products was considered as well.

The results are the scores based on H-phrase assessments and show that the toxicity potential from the use of supplementary cementitious materials has a positive impact on the overall results which are associated with the cement content in the mixture. As the cement content is reduced, the overall human toxicity impact is also reduced.



9. *Eco-Efficiency Portfolio and Index*

The BASF Eco-Efficiency portfolio was developed to graphically depict both economic and environmental results on a single matrix. The total environmental impact is plotted against total costs; both values are expressed in terms of person time. The eco-efficiency is inversely proportional to the distance from an alternative to the origin (0, 0). A diagram of the Eco-Efficiency Index shows these distances for all alternatives.

Alternatives whose Eco-Efficiency Index are within a specified sensitivity (normally 10%) are considered to be equally eco-efficient. Because the Eco-Efficiency Portfolio always includes the point (0, 0), it is normal for most alternatives to be located closer to the lower left corner; this is not an indication of low eco-efficiency.

Figure 5 displays the eco-efficiency portfolio for the base case analysis and shows the results when all individual environmental categories are combined into a single relative environmental impact and then balanced with the life cycle cost impact. Since environmental impact and cost are equally important, the most eco-efficient alternative is the result closest to the upper right hand corner of the diagram. This is also shown in the index located to the right of the portfolio clearly showing the Green Sense® Concrete mixture as the most eco-efficient alternative.

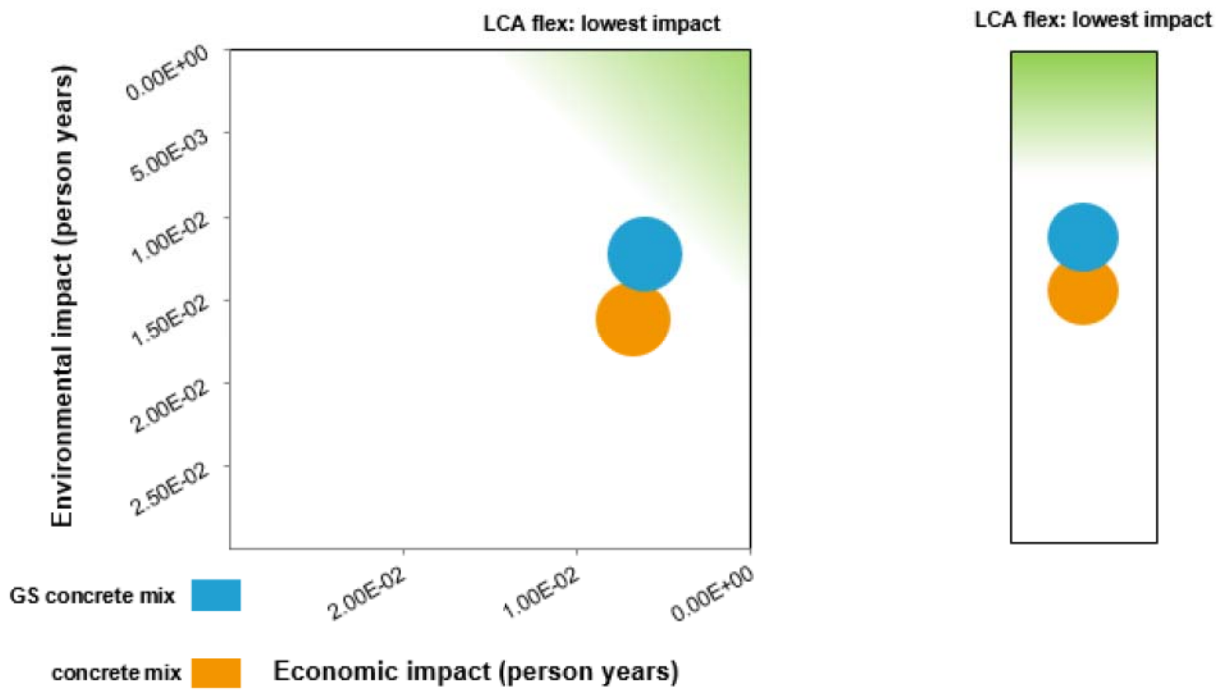


Figure 5: Eco-Efficiency Portfolio and Index for a Green Sense® Concrete comparison

9.1. Sensitivity Analysis

In order to investigate the robustness of the study results and to avoid false interpretations of results based on assumptions, sensititivty analyses may be carried out by investigating the effect of specific parameter choices on the overall impact results. The primary parameters that would be of concern are displayed in the relevance check (figure 4) for each of the Green Sense® Concrete Eco-Efficiency studies. For concrete mixture designs, the primary inputs that generally affect the relevance check results will be cement content, transportation distances and modes, availability of fresh water resources and human toxicity potential. Any results from a sensitivity analyses conducted during the study will be presented in the final report.

10. Data Quality Assessment

Data Quality Statement: The process of developing a BASF EEA is often iterative and so as data is collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the inputs/outputs. The BASF EEA methodology calls for an ongoing consideration of the appropriateness, accuracy and preciseness of input data throughout the study. Geographic, technological and temporal appropriateness of the data is considered in the selection of input data. Sensitivity calculations may be used to determine whether any specific inputs, assumption or life cycle inventory are critical for result stability.

All LCI data sets used in the mastersheet have been collected from the GaBi database version 6.115, BASF and customer specific product data.

Regional data is important for the generation of results relative to the specific area or location where the concrete mixtures are developed and placed. Therefore, three regions have been set up initially based on data quality and availability. These three regions are North America, Europe and the Middle East. Certain binders and utilities that would generate the most uncertainty in a study have been identified and separated within the mastersheet to reduce uncertainty within these inputs.

There were no significant critical uncertainties from this study that would limit the findings or interpretations of this study. The data quality, relevance and sensitivity of the study supports the use of the input parameters and assumptions as appropriate.

11. Limitations of EEA Study Results

These Eco-Efficiency analysis results and its conclusions are based on the specific comparison of the production, use, and disposal, for the described functional unit, alternatives and system boundaries. Transfer of these results and conclusions to other production methods or products is expressly prohibited. In particular, partial results may not be communicated so as to alter the meaning, nor may arbitrary generalizations be made regarding the results and conclusions.

12. Validation

This Eco-Efficiency analysis was performed by BASF according to the methodology validated by NSF International under the requirements of Protocol P352. More information on BASF's methodology and the NSF validation can be obtained at http://www.nsf.org/ecoefficiency.

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