SustainableSolutions
CORPORATION

IMA-NA Calcium Carbonate Life Cycle Assessment

Prepared For:

Industrial Minerals Association
North America

November 2016

155 Railroad Plaza, Suite 203
Royersford, PA 19468 USA
T: 610 569 1047
F: 610 569 1040
www.SustainableSolutionsCorporation.com

Life Cycle Assessment
Industrial Minerals Association North America
Calcium Carbonate

November 2016

CONFIDENTIAL – FOR INTERNAL USE ONLY

Commissioned by Industrial Minerals Association North America
LCA Practitioner: Sustainable Solutions Corporation

Conducted according to ISO 14044 International Standard

Life Cycle Assessment

IMA-NA

Calcium Carbonate

Executive Summary

This report documents the details and data used to develop a cradle-to-gate life-cycle assessment (LCA) of calcium carbonate using inventory and processing data obtained directly from the North American region of the Industrial Minerals Association (IMA-NA). The four companies included in this analysis are IMERYS, Carmeuse, Columbia River Carbonates, and Omya. The products analyzed are the following variations of the calcium carbonate product: screened grade, coarse dry 30 micron, coarse dry 20 micron, fine slurry 3 micron, and fine treated 2 micron.

The objective of IMA-NA in commissioning this study was to develop an industry average LCA for North American-mined/quarried calcium carbonate to provide the members with a detailed understanding of the environmental impacts of mined calcium carbonate throughout the cradle-to-gate extraction and production to examine opportunities for process and material improvements as well as provide potential public information.

LCA is a rigorous study of the inputs and outputs at each stage in the life cycle of a product, which provides a scientific basis for evaluating the resulting potential environmental impacts. LCA is an alternative to the single-criterion decision-making that currently guides many environmental choices. It enables a deeper understanding of the environmental footprint, which benefits manufacturers in improving their product's environmental performance and their manufacturing processes, as well as enables consumers to make more informed decisions on products and materials.

Goals

The goals of this study were to:

- Identify and quantify the potential environmental impacts and embodied energy associated with each cradle-to-gate stage in the production of calcium carbonate manufactured at the participating sites.
- Illustrate how the results from this study relate to the results of the European calcium carbonate study.
- Serve as the basis for the publication of relevant environmental literature. The literature will enable communication of environmental performance information to existing and potential customers and other external stakeholders.

Methodology

This study was conducted according to the life cycle inventory (LCI) and life cycle impact assessment (LCIA) standards established by the International Organization for Standardization (ISO) life cycle assessment standards ISO 14040 series. The geographic boundary for this study is primarily North America. This is a cradle-to-gate LCA study that examines each calcium carbonate product (screened grade, coarse dry 30 micron, coarse dry 20 micron, fine slurry 3 micron, and fine treated 2 micron) produced at the IMERYS, Carmeuse, Columbia River Carbonates, and Omya facilities in North America from the support materials extraction through final product processing.

For this life cycle assessment, Sustainable Solutions Corporation collected specific data on energy and material inputs, waste, water use, particulate emissions, and transportation impacts for calendar year 2014 (2015 for Omya's Sylacauga plant) at each of the quarry and plant facilities. Production data was allocated for these inputs in collaboration with process experts. The USLCI and US ecoinvent databases served as the source of all secondary inventory data for energy, transportation, and support materials processes not directly collected from IMA-NA and upstream vendors. Where data was not available in these databases, data and information from literature reviews and support material suppliers were used to identify proxy materials in the database.

The LCI results were characterized into impact assessment indicator categories using a subset of the US Environmental Protection Agency's (EPA) Tools for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI 2.1) factors as well as cumulative energy demand.

Key Findings

Depending on the particular grade of calcium carbonate, either the plant processing and quarry operation stages of the products generally contribute the most to the cradle-to-gate life cycle impacts. This is mainly due to the high electricity use in the plant processing stage and the explosives used in the quarry operations stage. The fine products require significantly more processing so their processing impacts are higher than the other products.

Out of the support materials, stearic acid and dispersant have the largest life cycle impacts for the fine treated and fine slurry products, respectively. The screened and coarse dry products require a significantly smaller number of support materials, so the largest impacts for those products stem from either the conveyor belt or steel screen. Barge transport of the input stone from the quarry and stearic acid in particular have a significant influence on a product's support material transportation impacts.

Recommendations

IMA-NA calcium carbonate producers should consider using the results of this life cycle impact assessment study for reducing impacts and product improvements including:

- To better understand the life cycle impacts of calcium carbonate to see how their particular company compares to the North American average for energy, water, waste, and emissions.
- R&D personnel at participating companies can use the LCA results as a tool to evaluate lower impact support materials, suppliers, and process design within the physical and chemical constraints of the required product.
- Continue to track energy, water, and waste and evaluate opportunities to reduce consumption and related impacts within the quarry and plant operations.
- Discuss opportunities with suppliers to further reduce impacts from support materials.
- Submit this LCA study to USLCI after critical review to allow this data to be used for other LCAs
- Develop literature to communicate the results of this study to external customers and stakeholders

Table of Contents

Executive Summary 3
List of Figures 7
List of Tables 9
1.0 Introduction 11
  1.1 Background 11
  1.2 Overview of Life Cycle Assessment 11
2.0 Goal and Scope Definition 13
  2.1 Goal of the Study 13
  2.2 Functional Unit 14
  2.3 System Boundary 14
    2.3.1 Cut-off Criteria 16
3.0 Data Sources and Modeling Software 16
  3.1 Data Quality 16
  3.2 Data Sources 18
  3.3 Modeling Software 23
4.0 Life Cycle Inventory Analysis 24
  4.1 Support Materials Overview 24
  4.2 Extraction and Processing Overview 25
    4.2.1 Quarrying 25
    4.2.2 Plant Processing 25
    4.2.3 Extraction and Processing Inventory 25
  4.3 Cradle-to-Gate Flow Data 26
5.0 Life Cycle Impact Assessment (LCIA) 27
  5.1 Impact Categories/Impact Assessment 27
  5.2 Selected Impact Categories 27
  5.3 Allocation and Assumptions 29
6.0 Calcium Carbonate LCA Results 31
  6.1 Quarry Impacts 31
    6.1.1 Quarrying Energy and Carbon Analysis 31

6.1.2 Additional Environmental Impacts from Quarry Processing 33
6.1.3 Plant Energy and Carbon Analysis 35
6.1.4 Additional Environmental Impacts from Plant Processing 37
6.2 Support Material Impacts 38
6.2.1 Quarry Support Materials 38
6.2.2 Plant Production Support Materials 40
6.3 Overall Environmental Impact 43
6.3.1 Overall Energy and Carbon Life Cycle Impacts 43
6.3.2 Overall Environmental Impacts using TRACI 44
6.4 All Calcium Carbonate Products Comparison 50
7.0 Additional Analysis 52
7.1 Distribution Scenarios 52
7.2 European Data Comparison 53
8.0 Limitations 56
9.0 Conclusions 56
10.0 Recommendations 57
Appendix A: Process Flow Diagrams 58
Appendix B: Sensitivity Analysis 61
B.1 Electricity Sources 61
B.2 Transportation Methods 63
Appendix C: US LCI Submission SI Conversion 64
C.1 Support Materials Overview 64
C.2 Extraction and Processing Overview 65
Appendix D: Critical Review by Independent Third Party 66

List of Figures

Figure 1.1 - The Four Stages of Life Cycle Assessment......12
Figure 2.1 - System Boundary for Calcium Carbonate......15
Figure 6.1 - Life Cycle Stage Control Diagram......31
Figure 6.2 - CED (left) and GWP (right) to Extract Calcium Carbonate in the Quarry......33
Figure 6.3 - TRACI analysis of Quarry Processing (per dry ton of product)......34
Figure 6.4 - Energy Used to Manufacture the Coarse Dry 30M (left) and Fine Treated 3M (right) Products......35
Figure 6.5 - Global Warming Potential in the Manufacture of the Coarse Dry 30M (left) and Fine Treated 3M (right) Products......36
Figure 6.6 - Calcium Carbonate Product Processing Phase Comparison......37
Figure 6.7 - Support Material Impacts for Quarry......39
Figure 6.8 - Quarry Explosives Impact Distribution......39
Figure 6.9 - Support Material Impacts for Coarse Dry 30M......40
Figure 6.10 - Support Material Impacts for Fine Treated 3M......42
Figure 6.11 - Cumulative Energy Demand (CED) for the Various Life Cycle Stages of Calcium Carbonate (MJ/ton)......43
Figure 6.12 - Global Warming Potential (GWP) for the Various Life Cycle Stages of Calcium Carbonate (kg CO_2 eq/ton product)......44
Figure 6.13 - Environmental Impacts of Coarse Dry 30M Calcium Carbonate (TRACI Impact Assessment Methodology)......46
Figure 6.14 - Environmental Impacts of Fine Treated 3M (TRACI Impact Assessment Methodology)......47
Figure 6.15 - Overall TRACI Impacts of the Screened Grade Product......48
Figure 6.16 - Overall TRACI Impacts of Coarse Dry 20M Product......49
Figure 6.17 - Overall TRACI Impacts of Fine Slurry 3M Product......50
Figure 6.18 - Environmental Impacts of Calcium Carbonate Products (per Dry Ton of Product)......51
Figure 7.1 - Calcium Carbonate Distribution Comparison......52
Figure 7.2 - IMA-EU and IMA-NA Coarse Comparison......53
Figure 7.3 - IMA-EU and IMA-NA Slurry Comparison......54
Figure 7.4 - IMA-EU and IMA-NA Treated Comparison......55
Figure A.1 - Mining/Quarrying Process Flow Diagram for CaCO3......58
Figure A.2 - Dry Grinding Process Flow Diagram for CaCO3......59
Figure A.3 - Wet Grinding and Drying and Treating Process Flow Diagram for $CaCO_3$......60

Figure B.1 - Coarse Dry 30M and Fine Treated 3M Electricity GWP (kg CO2 eq/dry ton) Comparison 61

Figure B.2 - US Electricity Grid TRACI Comparisons 62

Figure B.3 - Plant Support Material Transportation GWP (kg CO2 eq) Impact Comparison per Ton of Product 63

List of Tables

Table 2.1 - Calcium Carbonate Product Details 14
Table 2.2 - System Boundary Description........ 15
Table 3.1 - Data Sources for Calcium Carbonate Quarry Operations (Support Materials)........ 19
Table 3.2 - Data Sources for Calcium Carbonate Processing (Support Materials) 20
Table 3.3 - Energy, Fuel, Transportation and Waste Data Sources for Calcium Carbonate 22
Table 4.1 - Calcium Carbonate Quarry Support Materials........ 24
Table 4.2 - Calcium Carbonate Plant Support Materials........ 24
Table 4.3 - Quarry Materials and Fuels Inventory (per ton of product)........ 26
Table 4.4 - Plant Manufacturing Process Materials and Fuels Inventory (per ton of product)........ 26
Table 6.1 - Energy use During the Manufacturing and Shipping Processes........ 33
Table 6.2 - TRACI Analysis of Quarry Processing (per dry ton of product) 34
Table 6.3 - Energy use During the Product Plant Processing (MJ/ dry ton of product) 35
Table 6.4 - GWP from the Plant Processing (kg CO_2 eq/dry ton product)........ 36
Table 6.5 - Calcium Carbonate Product Processing Phase Comparison (per dry ton of product) 37
Table 6.6 - Support Material Impacts for Quarry (per dry ton of product)........ 38
Table 6.7 - Support Material Impacts for Coarse Dry 30M (per dry ton of product) 40
Table 6.8 - Support Material Impacts for Fine Treated 3M (per dry ton of product) 41
Table 6.9 - Cumulative Energy Demand (CED) for Calcium Carbonate Products(MJ/dry ton of product) 43
Table 6.10 - Global Warming Potential (GWP) Values for Calcium Carbonate Products (kg CO_2 eq/dry ton of product) 44
Table 6.11 - Environmental Impacts of Coarse Dry 30M Calcium Carbonate (per dry ton of product) (TRACI Impact Assessment Methodology) 45
Table 6.12 - Fine Treated 3M Environmental Impacts (per dry ton of product) using the TRACI Impact Methodology........ 47
Table 6.13 - Overall TRACI Impacts of the Screened Grade Product (per dry ton of product)........ 48
Table 6.14 - Overall TRACI Impacts of Coarse Dry 20M Product (per dry ton of product)........ 49
Table 6.15 - Overall TRACI Impacts of Fine Slurry 3M Product (per dry ton of product) 50
Table 6.16 - Overall Environmental Impacts for Each Calcium Carbonate Product (per dry ton of product) 51
Table 7.1 - Calcium Carbonate Distribution Comparison........ 52
Table 7.2 - IMA-EU and IMA-NA Coarse Comparison 53

Table 7.3 - IMA-EU and IMA-NA Slurry Comparison......54
Table 7.4 - IMA-EU and IMA-NA Treated Comparison......55
Table B.1 - Coarse Dry 30M and Fine Treated 3M Electricity GWP (kg CO2 eq/dry ton) Co......61
Table B.2 - US Electricity Grid TRACI Comparisons......62
Table B.3 - Plant Support Material Transportation GWP (kg CO_2 eq) Impact Comparison per ton of product......63
Table C. 1 - Calcium Carbonate Quarry Support Materials......64
Table C. 2 - Calcium Carbonate Plant Support Materials......64
Table C. 3 - Quarry Materials and Fuels Inventory (per ton of product)......65
Table C. 4 - Plant Manufacturing Process Materials and Fuels Inventory (per ton of product)......65

1.0 Introduction

Life cycle assessment (LCA) is a powerful tool used to quantify the environmental impacts associated with the various stages of a product's life. Section 1 provides a background and overview of LCA methodology and benefits.

1.1 Background

The use of LCA is growing rapidly across several markets such as construction, food, and household goods. IMA-NA calcium carbonate producers recognize the benefits of communicating credible, science-based and transparent environmental information about their product. This report will baseline and benchmark one short ton of the calcium carbonate products to assist with measuring and understanding the environmental impacts of calcium carbonate across the cradle to gate life cycle.

1.2 Overview of Life Cycle Assessment

Life Cycle Assessment (LCA)[1] is an analytical tool used to comprehensively quantify and interpret the environmental flows to and from the environment (including emissions to air, water and land, as well as the consumption of energy and other material resources) over the entire life cycle of a product (or process or service). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product and an accurate picture of the true environmental tradeoffs in product selection.

The standards in the ISO 14040-series set out a four-phase methodology framework for completing an LCA, as shown in Figure 1: (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment, and (4) interpretation. An LCA starts with an explicit statement of the goal and scope of the study; the functional unit; the system boundaries; the assumptions, limitations and allocation methods used; and the impact categories chosen. In the inventory analysis, a flow model of the technical system is constructed using data on inputs and outputs. The input and output data needed for the construction of the model are collected (including resources, energy requirements, emissions to air and water, and waste generation for all activities within the system boundaries). Then, the environmental loads of the system are calculated and related to the functional unit, to finalize the flow model. Inventory analysis is followed by impact assessment, where the LCI data are characterized in terms of their potential environmental impact (e.g., acidification, eutrophication and global warming potential effects). The impact assessment phase of LCA is used to evaluate the significance of potential environmental impacts based on the LCI results. The impact assessment data are interpreted and

---

[1] This introduction is based on international standards in the ISO-14040 series, *Environmental Management – Life Cycle Assessment.*

validated by sensitivity analysis by the LCA practitioner to provide useful data to the manufacturer's and industry that commissioned the LCA.

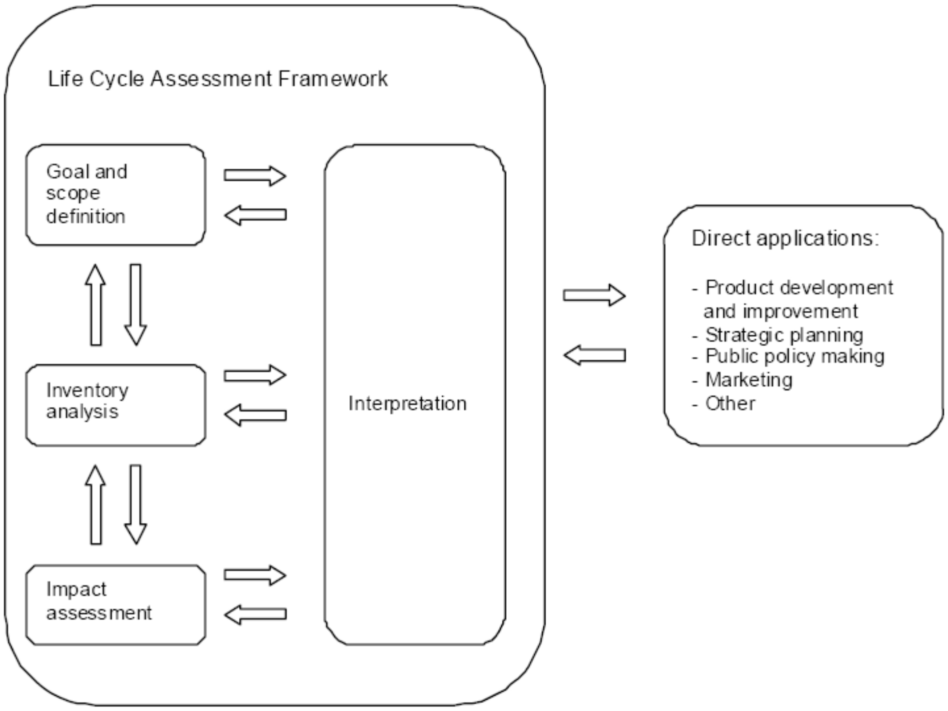

Figure 1.1 - The Four Stages of Life Cycle Assessment

The working procedure of LCA is iterative, as illustrated with the back-and-forth arrows in Figure 1.1. The iteration means that information gathered in a later stage can cause effects in a former stage. When this occurs, the former stage and the following stages have to be reworked, taking into account the new information. Therefore, it is common for an LCA practitioner to work at several stages at the same time.

This LCA study is characterized as a "cradle-to-gate" study, examining the calcium carbonate from the raw material extraction through the final product processing. For this life cycle assessment, Sustainable Solutions Corporation (SSC) collected specific data on energy and material inputs, waste, water use, emissions, and transportation impacts for the IMA-NA calcium carbonate production in the IMERYS, Carmeuse, Columbia River Carbonates, and Omya facilities for the calendar year 2014, with the exception of Omya's Sylacauga site which uses 2015 data.

This LCA was conducted using SimaPro software[2] with the National Renewable Energy Lab (NREL) US LCI database[3] serving as the primary source of life cycle inventory data for electricity and transportation background data sets. The remaining support material ingredients and processes not

---

[2] SimaPro v8.0.3 Multi user. PRé Consultants. 2013.

[3] US LCI Database for Life Cycle Engineering, National Renewable Energy Laboratory, Lakewood, CO, 2008

directly collected from participating members were modeled using various data sets from USLCI and US ecoinvent databases[4], private SSC LCI databases, and published reports. Data from European databases was adapted using US electricity impacts. The TRACI version 2.1 impact assessment methodology was used to calculate the environmental impacts in this LCA. TRACI was developed by the US Environmental Protection Agency (EPA) as a tool to assist in impact analysis in Life Cycle Assessments, process design, and pollution prevention. Impact categories include:

1. Global Warming Potential
2. Acidification
3. Carcinogens
4. Non-Carcinogens
5. Respiratory Effects
6. Eutrophication
7. Ozone Depletion
8. Ecotoxicity
9. Smog
10. Fossil Fuel Depletion

Potential benefits of a life cycle assessment include: better materials sourcing, manufacturing process environmental impact reduction, education, evaluation of support materials, affects to product standards, decreased air emissions, waste reduction, increased recycling, reduced water use, and cost savings, among many others.

2.0 Goal and Scope Definition

The nature of life cycle assessment is to include a wide range of inputs associated with the product being analyzed. Constraining the LCA scope is an essential part of the study. The following section defines the goal, scope, and boundaries of this LCA study.

2.1 Goal of the Study

The goal of this analysis is to identify and quantify the environmental impacts associated with each stage in the cradle-to-gate life cycle of the calcium carbonate, including support material extraction, and processing.

Intended Uses

LCA is a tool that can effectively be applied for manufacturing process improvements, education and market support, environmental management, and sustainable reporting. IMA-NA calcium carbonate producers, whom are the primary audience of the study, intend to use the study results

---

[4] ecoinvent v. 2.2. Swiss Centre for Life cycle Inventories. www.ecoinvent.org.

mainly for the following purposes:

- Provide a baseline industry wide LCA in order to understand and evaluate the impacts of the calcium carbonate across the product cradle-to-gate life cycle.
- Illustrate how calcium carbonate from IMA-NA compares to existing European data.
- Develop a confidential LCA report according to ISO standards, to serve as an input for published material.
- Evaluate possible process improvements in the manufacture of calcium carbonate. Based on the results, manufacturers can evaluate alternate support materials, and operations opportunities.
- As a tool to illustrate the reduced environmental impacts to regulatory agencies (state or local environmental agencies or the U.S. EPA) as needed.
- To meet future requirements for green purchasing programs for the United States or Canadian governments, corporations, or other businesses.
- Develop literature to communicate the results of this study to external customers and stakeholders.

2.2 Functional Unit

All flows to and from the environment within the system boundary (see Section 2.3 below) are normalized to a unit summarizing the function of the system. Since calcium carbonate has numerous uses and applications, this is a cradle-to-gate study with a declared unit of one short ton. This functional unit is consistent with the goal and scope of the study. Table 2.1 lists specific details of the calcium carbonate.

Table 2.1 - Calcium Carbonate Product Details

Company	Screened	Coarse, Dry, ~20 micron	Coarse, Dry, ~30 micron	Fine, Slurry, 3 micron	Fine, Treated, 3 micron
Columbia River Carbonates	Woodland, WA	Woodland, WA	-	Woodland, WA	Woodland, WA*
Imerys	Sylacauga, AL	Sylacauga, AL	Sylacauga, AL	Sylacauga, AL	Sylacauga, AL
Omya	Perth, Ontario	Lucerne Valley, CA	St Armand, Quebec	Sylacauga, AL	Sylacauga, AL
Carmeuse	Middletown, VA	Chatsworth, GA	Chatsworth, GA	-	-

**Only two participating members produced the fine, treated, 3 micron product. To maintain confidentiality throughout the industry, Columbia River Carbonates provided data up through the grinding processing for a 3 micron fine product to provide a weighted average amount of three producers. The further drying and treatment steps were provided by the remaining two producers and weighted between them. These two steps were then aggregated together to prevent back-calculating of data.*

The functional unit determines the environmental impacts and is the basis for comparison in an LCA. It provides a unit of analysis and comparison for all environmental impacts.

2.3 System Boundary

This project considers the cradle-to-gate life cycle activities from resource extraction through product processing. Figure 2.1 defines the system boundary calcium carbonate. The study system boundary includes the transportation of major inputs to (and within) each activity stage including the shipment of quarry products to the processing sites, based on logistics data provided by IMA-NA, by common modes, as well as transportation to a landfill or recycling for waste products. Any combusted fuels and purchased electricity is included in the system boundary. The extraction, processing and delivery of purchased primary fuels, e.g., natural gas and primary fuels used to generate purchased electricity, are also included within the boundaries of the system. Purchased electricity consumed at the various site locations is modeled based on US grid averages, using the models published in the NREL US LCI database.

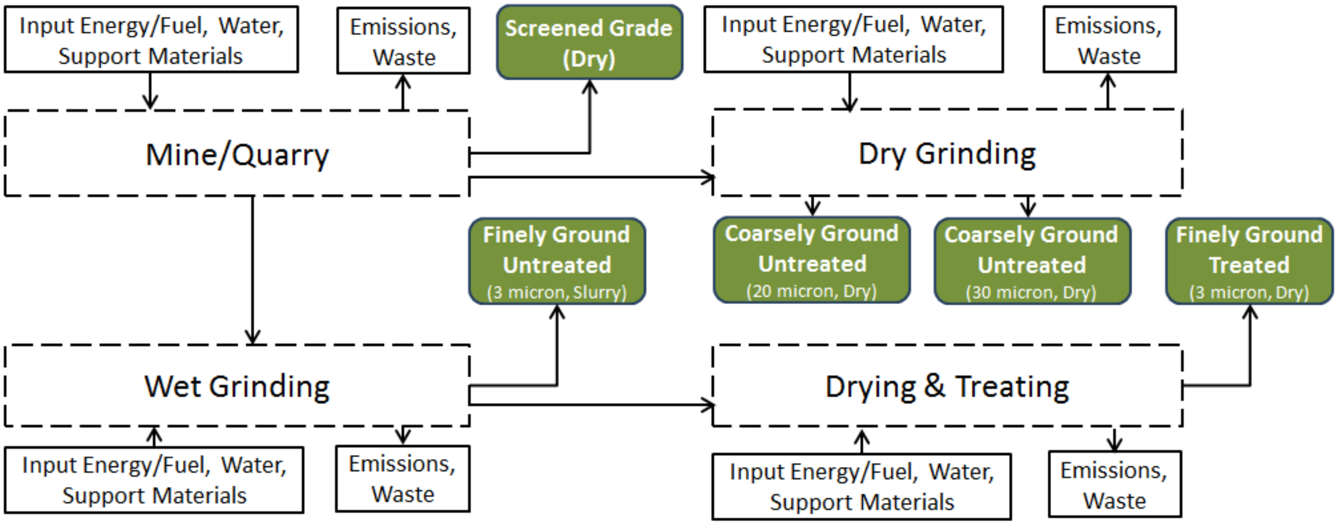

Figure 2.1 - System Boundary for Calcium Carbonate

Both human activity and capital equipment were excluded from the system boundary. The environmental effects of manufacturing and installing capital equipment and buildings have generally been shown to be minor relative to the throughput of materials and components over the useful lives of the buildings and equipment. Human activity involved in the mining and processing of calcium carbonate and their component materials will have an impact on the environment. However, the data collection required to properly quantify human involvement is particularly complicated, and allocating such flows to the production of the calcium carbonate products as opposed to other societal activities, was not feasible for a study of this nature. Typically, human activity is only considered within the system boundary when value-added judgments or substituting capital for labor decisions is considered to be within the scope of the study; however, these types of decisions are outside this study's goal and scope. The details of the data excluded from the system boundary can be found in the subsequent inventory sections.

Table 2.2 - System Boundary Description

Included	Excluded
Support material acquisition Transport of raw materials Processing of quarry rock Overhead energy used in production (lighting, heating, cooling, etc.) at quarry and plant Manufacturing waste and emissions	Construction of capital equipment Maintenance of operation and support equipment Human labor and employee commute Final product shipping Packaging Product use Product disposal

2.3.1 Cut-off Criteria

Processes whose total contribution to the final results, with respect to their mass and in relation to all considered impact categories, is less than 1% can be neglected. The sum of the neglected processes may not exceed 5% by mass and by 5% of the considered impact categories. For that a documented assumption is admissible.

For Hazardous Substances, as defined by the U.S. Occupational Health and Safety Act, the following requirements apply:

- The Life Cycle Inventory (LCI) of hazardous substances will be included, if the inventory is available.
- If the LCI for a hazardous substance is not available, the substance will appear as an input in the LCI of the product, if its mass represents more than 0.1% of the product composition.
- If the LCI of a hazardous substance is approximated by modeling another substance, documentation will be provided.

This LCA is in compliance with the cut-off criteria since no known processes were neglected or excluded from this analysis outside of the specific items listed under “excluded” in Table 2.2.

3.0 Data Sources and Modeling Software

The quality results of an LCA study are directly dependent on the quality of input data used in the model. This section describes the data quality guidelines used in this study, the sources from which the data was selected, the software used to model the environmental impacts, and any data excluded from the scope of the study.

3.1 Data Quality

Wherever secondary data are used, the study adopts critically reviewed data for consistency, precision, and reproducibility to limit uncertainty. The data sources used are complete and representative of North America in terms of the geographic and technological coverage and are a recent vintage (i.e. less than ten years old). Any deviations from these initial data quality requirements for secondary data are documented in the report.

The results of an LCA are only as good as the quality of input data used. Important data quality factors include precision (measured, calculated or estimated), completeness (e.g., unreported emissions or excluded flows), consistency (uniformity of the applied methodology throughout the study), and reproducibility (ability for another researcher to reproduce the results based on the methodological information provided). The primary data from the manufacturer was from the latest data available. Each dataset used was taken from SimaPro databases, either US LCI or ecoinvent. These databases are widely distributed and referenced within the LCA community and are partially or fully critically reviewed.

Time-Related Coverage

The primary data was collected from the IMA-NA members for the latest full calendar year of data, 2014 (2015 for Omya Sylacauga data). All other secondary data processes were based on data less than ten years old.

Geographical Coverage

The primary data collected covers all eight production facilities throughout North America. An overall US electricity grid inventory was used for each facility.

Technology Coverage

Whenever possible, the inventory process with the most recent and applicable technology was chosen for the calcium carbonate LCA model.

Precision

The data used for primary data are based on direct information sources of the manufacturer. The energy and water usage data was collected directly from the utility meters, and the allocation was based on an automated machine run-time and energy use tracking system at the plant. Therefore, the precision for primary data is considered high; however, the uncertainty of the primary data has not been quantified.

Secondary data sets were used for raw materials extraction and processing, end of life, transportation, and energy production flows. The US ecoinvent database was used for most of the raw material data sets. Since the inventory flows for ecoinvent processes are very often accompanied by a series of data quality ratings, a general indication of precision can be inferred. Using these ratings, the data sets used generally have medium-to-high precision. Precision for the datasets used from the US LCI database was not formally quantified. However, many data sets from the US LCI were developed based on well-documented industry averages with data quality indicators provided for each flow.

Completeness

The processes modeled represent the specific situations in the calcium carbonate life cycle. System boundaries and exclusions are clearly defined in the sections above, and no other data gaps were identified.

Consistency

Primary data was collected from the IMA-NA companies with most data, if not all, tracked by World Class Manufacturing automated systems and records. Since most of the data are annually reported, the consistency is considered high. Secondary data was consistently modeled using either US LCI or ecoinvent databases, as available. Proxies were only identified and used if secondary data was not available in these or other databases. This methodology provides consistency throughout the model.

Reproducibility

Most datasets are from nationally accepted and publicly available databases, ensuring reproducibility by an average practitioner. Confidential data from the plant would inhibit reproducing these results without access to the data.

Representativeness

The representativeness of the datasets is chosen to be representative of North America, average technologies of the major producers and distributors and of recent and modern vintage.

Uncertainty

Most of the secondary data sets in US LCI and ecoinvent databases have some uncertainty information documented and varies per model. Uncertainty for primary data was not quantified. However, the collected data and allocation methodologies were judged by the operations personnel to be accurate, so the uncertainty is considered low.

The primary data from the manufacturer was from the latest data available, incorporating the most recent updates to the process into the model. Each dataset used was taken from SimaPro databases, either US LCI or ecoinvent. These databases are widely distributed and referenced within the LCA community. The datasets use relevant yearly averages of primary industry data or primary information sources of the manufacturer and technologies. The uncertainty of each dataset is not formally quantitatively known. Each dataset is from publicly available databases, ensuring reproducibility. The representativeness of the datasets is chosen to be representative of North America, average technologies of the major producers and distributors and of recent and modern vintage. Below is a more detailed description of the datasets used in the model of raw materials extraction and processing for the major components of Calcium Carbonate.

3.2 Data Sources

North America is considered as the geographic boundary of this study. The reference year is 2014, with the exception of Omya's Sylacauga plant for which the data are from 2015, since the primary IMA-NA calcium carbonate manufacturing data was gathered for that calendar year. Both primary and secondary LCI and metadata are used throughout the study. All secondary data are taken from literature, previous LCI studies, and life cycle databases. The US LCI database (www.nrel.gov/lci) is frequently used in this analysis. Much of the LCI data residing in the US LCI database pertain to common fuels – their combustion in utility, stationary and mobile equipment inclusive of upstream or pre-combustion effects (i.e. back to earth). Generally, these modular data are of a recent vintage (less than ten years old). This study draws on these data for combustion processes, electricity generation, and transportation on a regional North American basis. These data are free and publicly available, and thus, offer both a high degree of transparency and an ability to replicate the results of the study; however, there are limitations, as some processes are missing for some of the products available in this LCI database, creating an issue with respect to completeness.

When North American data was not available for a product or process, the European ecoinvent LCI database was utilized. This database contains over 3,500 LCI modules for processes and products, all of which have undergone peer review. The basic assumption when using these data is that North American and European production processes are generally similar, but that these data need to be adapted for North American circumstances (e.g., electricity grids, fuels, and transportation modes and distances need to be modified to better reflect the North American operations). Such adaptation was conducted whenever necessary.

Table 3.1 - Data Sources for Calcium Carbonate Quarry Operations (Support Materials)

Material Input (Quarry)	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Antifreeze	Ethylene glycol, at plant/US-EI 2.2	2010	Europe	Includes oxidation of ethylene oxide leads to three coproducts: ethylene glycol, diethylene glycol (DEG) and triethylene glycol (TEG).	Secondary
Explosives	Uses ecoinvent Blasting Process /US-EI 2.2	2003	Europe	Includes the raw material (explosive Tovex) and the emissions (calculated stoichiometric).	Secondary
Truck Battery	60% Lead, at regional storage/US-EI 2.2	2008	Europe	Blend of 25% primary and 75% secondary production and includes transportation.	Secondary
	40% Sulphuric acid, liquid, at plant/US-EI 2.2	2003	Europe	Includes average and state of the art technology used in European sulphuric acid production plant.	Secondary
Truck Filter	75% Chromium steel 18/8, at plant/US-EI 2.2	2007	Europe	Mix of differently produced steels and hot rolling.	Secondary
	25% Textile, woven cotton, at plant/US-EI 2.2	2007	Global	Yarn production and weaving	Secondary
Oil & Grease	Lubricating oil, at plant/US-EI 2.2	2003	Europe adapted to US conditions	Production out of diesel by hydrocracking, followed by distillation and dewaxing.	Secondary
Winterizing Agent	35% Naphtha, at refinery/US-EI 2.2	2003	Europe, adapted to US conditions	Includes average technology for processes on the refinery site.	Secondary
	65% Kerosene, at refinery/US-EI 2.2	2004	Switzerland, adapted to US conditions	All processes on the refinery site excluding the emissions from combustion facilities, including waste water treatment, process emissions and direct discharges to rivers.	Secondary

Table 3.2 - Data Sources for Calcium Carbonate Processing (Support Materials)

Material Input (Plants)	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Biocides	Biocides, for paper production, at plant /US-EI 2.2	2003	Europe adapted to US conditions	Mixture of two oxidizing agents (chlorine dioxide, hydrogen peroxide) and two highly toxic organics (dithiocarbamate, cyanazin).	Secondary
Conveyor Belt	Synthetic Rubber, at plant/US-EI 2.2	2003	Europe adapted to US conditions	Production of EPDM-rubber, production of EPDM elastomer, extrusion and vulcanisation of EPDM profile	Secondary
Dispersant	Polycarboxylates, 40% active substance, at plant/US-EI 2.2	2003	Europe adapted to US conditions	Includes material and energy input for the production of polycarboxylates out of acrylic acid and maleic anhydride. Transport and infrastructure have been estimated.	Secondary
Filter (Bags)	Polyethylene Terephthalate, granulate, bottle grade, at plant/US-EI 2.2	2003	Europe adapted to US conditions	Average data for the production of bottle grade PET out of ethylene glycol, PTA and amorphous PE	Secondary
Filter (Socks)	Propylene, granulate, at plant/US-EI 2.2	2010	Europe adapted to US conditions	Aggregated data for all processes from raw material extraction until delivery at plant. Data are from the Eco-profiles of the European plastics industry.	Secondary
Flotation Agent 1	50% Imidazole, production/ecoinvent 3	2013	Europe	Production of imidazole from glyoxal	Secondary
	50% Acetic Acid from acetaldehyde, at plant/US-EI 2.2	2007	Europe adapted to US conditions	Oxidation of acetaldehyde	Secondary
Flotation Agent 2	50% fatty acids from, vegetable oil/US-EI 2.2	2003	Europe adapted to US conditions	Includes energy consumption, water and raw materials and waste.	Secondary
	50% EDTA, ethylenediaminetetraacetic acid, at plant/ US-EI 2.2	2003	Europe adapted to US conditions	Production from ethylenediamine by alkaline cyanomethylation	Secondary
Grinding Media 1	90% Alumina, at plant/US LCI	2008	United States	Bayer process for extracting alumina from bauxite	Secondary
	10% Silica sand, at plant/ US-EI 2.2	2003	Germany, adapted to US conditions	Typical technology for Swiss production	Secondary
Grinding Media 2	Proprietary to supplier/ adapted from US-EI 2.2	2007	Location-specific	Mining process and operations from specific mineral	Secondary

Material Input (Plants)	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Heat Transfer Liquid	Ethylene Glycol/ecoinvent 3	2013	Europe	Oxidation of ethylene oxide	Secondary
Lube Oil	Lubricating oil, at plant/ US-EI 2.2	2003	Europe adapted to US conditions	Production out of diesel by hydrocracking, followed by distillation and dewaxing	Secondary
Shaker Screen (Steel)	Chromium steel 18/8, at plant/US-EI 2.2	2007	Europe adapted to US conditions	Mix of differently produced steels and hot rolling. Average of World and European production mix.	Secondary
Stearic Acid	50% fatty acids, from palm oil, at plant. Based on model "fatty acids from, vegetable oil"/US-EI 2.2	2003	Europe adapted to US conditions	Includes energy consumption, water and raw materials and waste.	Secondary
	50% fatty alcohol sulfate, palm oil, at plant/US-EI 2.2	2003	Europe adapted to US conditions	Production of fatty alcohol sulfonate out of palm oil	Secondary
Suspension Aid	40% Sodium hydroxide, 50% in H2O, membrane cell, at plant/US-EI 2.2	2003	Europe adapted to US conditions	Present state of technology used in European membrane cells	Secondary
	60% Acrylic acid, at plant/US-EI 2.2	2006	Europe adapted to US conditions	Production from propylene by two-step oxidation process	Secondary
Urethane Screen	60% Methylene diphenyl diisocyanate, at plant/US-EI 2.2	2010	Europe adapted to US conditions	Production out of phosgene, aniline and formaldehyde	Secondary
	40% Polyol ether, for rigid foam polyurethane production, at plant/USLCI	2008	North America	Potassium hydroxide catalyzed initiation of sucrose, followed by reaction with propylene oxide, filtering, and purification	Secondary
Water	Tap water, at user/US-EI 2.2	2005	Switzerland, adapted to US conditions	Infrastructure and energy use for water treatment and transportation to the end user	Secondary

Table 3.3 - Energy, Fuel, Transportation and Waste Data Sources for Calcium Carbonate

Process Input	Database(s)and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Electricity	Electricity, at Grid, US, 2008/US LCI	2011	North America	Representative of year 2008 mix of fuels used for utility electricity generation in US. Fuels include biomass, coal, petroleum, geothermal, natural gas, nuclear, solar, hydroelectric and wind energy sources.	Secondary
	Electricity, at grid, Eastern US, 2000/USLCI	2011	North America	Representative of year 2000 mix of fuels used for utility electricity generation in the Eastern U.S. Fuels include coals, fuel oil, nuclear, hydroelectric, and unconventional energy sources.	Secondary
	Electricity, at grid, Western US, 2000/USLCI	2011	North America	Representative of year 2000 mix of fuels used for utility electricity generation in the Western U.S. Fuels include coals, fuel oil, nuclear, hydroelectric, and unconventional energy sources.	Secondary
Natural Gas	Natural gas, combusted in industrial equipment/USLCI	2008	North America	Natural gas combusted in average industrial equipment	Secondary
Propane	Liquefied petroleum gas, combusted in industrial boiler/USLCI	2008	United States	LPG combustion in average industrial boiler	Secondary
Diesel	Diesel, combusted in industrial equipment/USLCI	2008	United States	Diesel combustion in industrial applications such as mobile refrigeration units, generators, pumps, and portable well-drilling equipment.	Secondary
Gasoline	Gasoline, combusted in equipment/USLCI	2008	United States	Gasoline combustion in equipment such as mobile refrigeration units, generators, pumps, and portable well-drilling equipment.	Secondary
Waste Fuel	Gasoline, combusted in equipment/US LCI	2008	United States	Gasoline combustion in equipment. Gas production not included.	Secondary

Transportation	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Barge Transport (tmi)	Transport, barge, diesel powered/USLCI	2008	United States	Combustion of diesel in barge	Secondary
Rail Transport (tmi)	Transport, train, diesel powered/USLCI	2008	United States	Combustion of diesel in a locomotive	Secondary
Truck Transport (tmi)	Transport, combination truck, diesel/USLCI powered/USLCI	2008	United States	Combustion of diesel in a combination truck	Secondary
Waste Disposal	**Database(s) and Source**	**Temporal Information**	**Regional Coverage**	**Technology Coverage**	**Data Type and Quality**
Inert to Landfill	Disposal, inert waste, 5% water, to inert material landfill/US-EI 2.2	2003	Switzerland, adapted to US conditions	Landfill with renaturation after closure. 50% of the sites feature a base seal and leachate collection system.	Secondary
Recycling	Recycling glass/US-EI 2.2	2007	Europe adapted to US conditions	Empty Process b/c of cutoff at recycling	Secondary
Limestone residue to Inert Landfill	Disposal, limestone residue, 5% water, to inert material landfill/ US-EI 2.2	2003	Switzerland, adapted to US conditions	Landfill with renaturation after closure. 50% of the sites feature a base seal and leachate collection system.	Secondary

3.3 Modeling Software

SimaPro v8.0 software was utilized for modeling the complete cradle-to-gate LCI for calcium carbonate. All process data including inputs (support materials, energy, and water) and outputs (emissions, solid waste, and finished calcium carbonate) are evaluated and modeled to represent each process that contributes to the production of the calcium carbonate products. The study's geographical and technological coverage has been limited to North America. SimaPro was used to generate life cycle impact assessment (LCIA) results utilizing the TRACI impact assessment methodologies as well as Cumulative Energy Demand. See Section 5.2 for a description of the selected LCIA categories and characterization measures used in this study.

4.0 Life Cycle Inventory Analysis

This section describes the cradle-to-gate life cycle inventory of the calcium carbonate products. Primary manufacturing data was collected from surveys completed by personnel from the participating IMA-NA companies for the 2014 calendar production year (with the exception of Omya's Sylacauga plant, which provided 2015 data). The participating companies provided resource transportation mode and distance data to support the calculation of support material transportation flows. The transportation LCI data from the US LCI database (ton-mile basis) were used to develop the resource transportation LCI profile.

4.1 Support Materials Overview

A thorough analysis of the support material inputs was completed for the inventory of this study. The calcium carbonate support materials are listed in Table 4.1 and Table 4.2.

Table 4.1 - Calcium Carbonate Quarry Support Materials

Support Materials (Quarry)	Unit	Quarry Amount
Oil & Grease (equipment maintenance)	gal	1.48E-02
Antifreeze	gal	2.07E-03
Explosives	lb	1.24E+00
Battery	lb	2.10E-03
Filters (air, oil, fuel)	lb	1.97E-02
Tires	lb	2.05E-02
Winterizing Agent	gal	7.67E-03

Table 4.2 - Calcium Carbonate Plant Support Materials

Support Materials (Plants)	Unit	Screened	Coarse 30μg	Coarse 20μg	Fine Slurry 3μg	Fine Treated 3μg
Input Stone from Quarry	ton	1.36E+00	1.04E+00	1.20E+00	1.41E+00	1.44E+00
Shaker Screen (Steel)	lb	2.74E-02	4.43E-03	2.39E-02	6.36E-05	1.39E-04
Conveyor Belt	ft	1.96E-03	1.53E-03	1.19E-03	7.91E-04	1.05E-03
Biocides	lb	-	-	-	6.37E-02	5.22E-02
Urethane Screen	lb	-	-	-	3.67E-03	3.00E-03
Flotation Agent	lb	-	-	-	2.00E+00	1.26E+00
Dispersant	lb	-	-	-	8.44E+00	6.91E+00
Grinding Media 2	lb	-	-	-	2.95E-01	2.41E-01
Stearic Acid	lb	-	-	-	-	2.43E+01
Grinding Media 1	lb	-	-	-	3.30E-01	5.48E-01
Suspension Aid	lb	-	-	-	1.59E-02	3.48E-02
Plastic Bag Filters	lb	-	-	-	1.17E-03	3.30E-02
Heat Transfer Fluid	lb	-	-	-	-	1.17E-02
Lube Gear Oil Grease	lb	-	-	-	-	8.70E-04
Sock Filters	lb	-	-	-	1.31E-03	1.07E-03

4.2 Extraction and Processing Overview

A detailed analysis of the quarry and plant processes was completed by Sustainable Solutions Corporation including a site visit on June 11 in 2015 at the Sylacauga site to observe and understand the extraction and processing operations. A process flow diagram is attached in Appendix A and illustrates all process steps, inputs, and outputs including material, energy, emissions, and wastes.

4.2.1 Quarrying

The quarrying process involves the mechanical extraction and primary crushing of calcium carbonate rock (marble, limestone, or chalk). After primary crushing, this rock is then crushed, screened, and sent to either wet or dry intermediate storage to be sent for more processing at the plants or separated as the **screened grade product**.

4.2.2 Plant Processing

At the plants, the crushed rock is sent to either wet or dry grinding. The dry grinding process can include jaw crushing, washing, impact crushing, ball milling, and classifying. This outputs both the **coarse dry untreated 30 micron and 20 micron** products. Wet grinding includes washing, wet milling, flotation, cycloning, a second wet milling or thickening, then on to mixing and wet fine grinding. This outputs the **fine ground untreated 3 micron slurry** product. After this process, the left over product is dried and treated to create the **fine ground treated 3 micron dry** product.

4.2.3 Extraction and Processing Inventory

To produce calcium carbonate, energy, water and support materials go into the process and waste and emissions are outputs. An inventory based on the weighted averages of the data collected from the four calcium carbonate producers (eight processing facilities) was created with the data allocated per one short ton of product. Allocation was conducted via total production mass across the participating facilities over the calendar year to best represent the market average in the industry. The weighted average quarrying operations was conducted by total mass produced of calcium carbonate rock for all participating quarries. This quarry weighted average served as the input to each grade of calcium carbonate production process. Allocation for each grade of ground calcium carbonate was conducted based on total mass produced among the manufacturers participating in the study. No other types of minerals are produced at each quarry or processing site so no co-product allocation was required. Table 4.3 and Table 4.4 detail the weighted average process inputs and outputs.

Table 4.3 - Quarry Materials and Fuels Inventory (per ton of product)

Energy Inputs (Quarry)	Unit	Quantity
Electricity	kWh	3.19E+00
Gasoline	L	1.21E-02
Diesel	L	1.40E+00
Waste Fuel Oil	gal	6.44E-02
Waste	**Unit**	**Quantity**
Waste stone/overburden to Earth	ton	1.05E+00
Waste stone/overburden to Recycle	ton	2.42E-02
Waste solids to Landfill	lb	3.89E-02
Waste solids to Recycle	lb	3.33E-03
Waste liquids to Recycle	gal	1.69E-02
Air Emissions	**Unit**	**Quantity**
Particulates to Air	lb	4.19E-02
Transportation	**Unit**	**Quantity**
Truck	ton-mile	3.50E-02

Table 4.4 - Plant Manufacturing Process Materials and Fuels Inventory (per ton of product)

Energy Inputs (Plants)	Unit	Screened	Coarse Dry 30µg	Coarse Dry 20µg	Fine Slurry 3µg	Fine Treated 3µg
Electricity (kWh)	kWh	1.61E+01	2.40E+01	3.69E+01	2.15E+02	3.04E+02
Natural Gas	L	4.73E+00	3.74E-01	2.32E-01	2.19E-02	2.76E+01
Propane	L	-	3.05E-01	-	-	-
Water	**Unit**	**Screened**	**Coarse Dry 30µg**	**Coarse Dry 20µg**	**Fine Slurry 3µg**	**Fine Treated 3µg**
Water Inflow	gal	-		4.47E-02	1.36E+01	2.74E+01
Water Outflow*	gal			4.47E-02	1.36E+01	2.74E+01
Waste	**Unit**	**Screened**	**Coarse Dry 30µg**	**Coarse Dry 20µg**	**Fine Slurry 3µg**	**Fine Treated 3µg**
Waste sand/mud to Earth	ton	1.65E-01	3.03E-02	2.46E-01	6.14E-02	1.34E-01
Waste to Landfill	lb	2.71E-02	-	-	2.15E+01	4.69E+01
Waste to Recycle	lb	2.07E-03	5.96E-03	2.51E-02	8.33E-03	8.04E-03
Air Emissions	**Unit**	**Screened**	**Coarse Dry 30µg**	**Coarse Dry 20µg**	**Fine Slurry 3µg**	**Fine Treated 3µg**
Particulates to Air	lb	6.29E-02	9.77E-04	2.88E+00	3.52E-02	3.29E-02
Transportation	**Unit**	**Screened**	**Coarse Dry 30µg**	**Coarse Dry 20µg**	**Fine Slurry 3µg**	**Fine Treated 3µg**
Truck	ton-mile	1.38E+00	3.99E+01	3.25E+01	8.71E+00	1.54E+01
Rail	ton-mile			1.57E+02	1.76E+02	1.46E+02
Barge	ton-mile			1.65E+02	1.85E+02	1.80E+02

*Water outflow is not tracked by plant operators. No process water is sent for municipal wastewater treatment but is evaporated or stored in retention ponds for reuse.

4.3 Cradle-to-Gate Flow Data

Each company provided transportation modes and distances for the quarry and processing support materials. The transportation modes considered were truck, rail, and barge. Quarry and processing waste was assumed to be sent 60 miles to an inert landfill unless otherwise stated. This gate-to-gate flow data were combined with resource extraction and processing data.

5.0 Life Cycle Impact Assessment (LCIA)

The environmental impacts of a product can be categorized and presented in many ways. This section briefly describes the methodology used to develop the impact assessment and defines the selected impact categories used to present the results. This section also lists assumptions of the study and describes the inherent limitations and uncertainty of the LCA results.

5.1 Impact Categories/Impact Assessment

As defined in ISO 14040:2006, "the impact assessment phase of an LCA is aimed at evaluating the significance of potential impacts using the results of the LCI analysis". In the LCIA phase, SSC modeled a set of selected environmental issues referred to as impact categories and used category indicators to aggregate similar resource usage and emissions to explain and summarize LCI results data. These category indicators are intended to "characterize" the relevant environmental flows for each environmental issue category to represent the potential or possible environmental impacts of a product system. The results are relative expressions of possible environmental impacts and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

ISO 14044 does not specify any specific methodology or support the underlying value choices used to group the impact categories. The value-choices and judgments within the grouping procedures are the sole responsibilities of the commissioner of the study.

The framework surrounding LCIA includes three steps that convert LCI results to category indicator results. These include the following:

1. Selection of impact categories, category indicators and models.
2. Assignment of the LCI results to the impact categories (classification) – the identification of individual inventory flow results contributing to each selected impact indictor.
3. Calculation of category indicator results (characterization) – the actual calculation of the potential or possible impact of a set of inventory flows identified in the previous classification step.

To maximize the reliability and flexibility of the results, SSC used an established impact methodology for assigning and calculating impacts. The Tools for Reduction and Assessment of Chemical and other environmental Impacts (TRACI) methodology was used for all calculations of environmental impact. TRACI was developed by the US EPA to assist in impact analysis in Life Cycle Assessments, process design, and pollution prevention.

5.2 Selected Impact Categories

While LCI practice holds to a consistent methodology, the LCIA phase is an evolving science and there is no overall generally accepted methodology for calculating all of the impact categories that might be included in an LCIA. Typically, the LCIA is completed in isolation of the LCI. The LCI involves the collection of a complete mass and energy balance for each unit process under consideration. Once completed, the LCI flows are sifted through various possible LCIA indicator methods and categories to determine possible impacts. Due to the North American focus of this LCA study, the TRACI LCIA methodology was used to characterize the study's LCI flows. Impact categories include:

1. *Ozone depletion* (kg CFC-11 eq) – Certain chemicals, when released into the atmosphere, can cause depletion of the stratospheric ozone layer, which protects the Earth and its inhabitants from ultraviolet radiation. This radiation can have a negative impact on crops, materials, and marine life, as well as contributing to cancer and cataracts. This impact measures the releases of those chemicals.
2. *Global warming* (kg CO_2 eq) – The methodology and science behind the Global Warming Potential calculation can be considered one of the most accepted LCIA categories. Because this study also tracks an overall life cycle carbon balance, the carbon dioxide emissions associated with biomass combustion are included in the Global Warming Potential calculation, but the sequestering of carbon is treated as a negative emission in the calculation as per the IPCC methodology. Carbon dioxide and other greenhouse gasses are emitted at every stage in the manufacturing process. These gasses can trap heat close to the Earth, contributing to global warming.
3. *Smog* (kg O_3 eq) – 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 indicator is expressed as a mass of equivalent ozone (O_3).
4. *Acidification* (kg SO_2 eq) – Acidification is a more regional rather than global impact affecting fresh water and forests as well as human health when high concentrations of SO_2 are attained. Acidification is a result of processes that contribute to increased acidity of water and soil systems. The acidification potential of an air emission is calculated on the basis of the mass of equivalent sulfur dioxide that can be produced and, therefore is expressed as potential H+ equivalents on a mass basis.
5. *Eutrophication* (kg N eq) – Eutrophication is the fertilization of surface waters by nutrients that were previously scarce. When a previously scarce or limiting nutrient is added to a water body, it leads to the proliferation of aquatic photosynthetic plant life. This may lead to the water body becoming hypoxic, eventually causing the death of fish and other aquatic life. This impact is expressed on an equivalent mass of nitrogen (N) basis.
6. *Human Health: Carcinogens & Non-carcinogens* (CTU_h) – This impact assesses the potential health impacts of more than 200 chemicals. These health impacts are general, based on emissions from the various life cycle stages, and do not take into account increased exposure that may take place in manufacturing facilities. These impacts are expressed in terms of Comparative Toxic Units (CTU_h). For human health this represents the estimated increase in morbidity in the total human population per kg of chemical emitted.
7. *Respiratory effects* (kg $PM_{2.5}$ eq) – This impact methodology assess the impact of increasing concentrations of particulates on human health. Most industrial and transportation processes create emissions of very small particles, which can damage lungs and lead to

disease and shortened lifespans. This impact is expressed in terms of $PM_{2.5}$ (particulates that are 2.5 microns or less in diameter).

8. *Ecotoxicity* (CTU_e) – Many chemicals, when released into the environment, can cause damage individual species and to the overall health of an ecosystem. Ecotoxicity measures the potential damage to the ecosystem that would result from releasing that chemical into the environment. This impact is measured in terms of Comparative Toxic Units (CTUe) and provides an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of chemical emitted.
9. *Fossil Fuel Depletion* (MJ surplus) – Maintaining fossil fuel resources for future generations is an essential part of sustainable development. This impact category measures the depletion of those resources in terms of megajoules (MJ). Fossil fuels are used as energy sources as well as raw materials for chemical productions.

While the TRACI methodology supports fossil fuel depletion (on a global scale), it does not readily report primary energy use as an impact category. Primary energy use on a cumulative energy demand basis is tabulated and summarized as an impact category directly from the LCI flow results. Energy use is a key impact indicator over which manufacturers are likely to assert a considerable level of control and, therefore, is a good internal target for resource conservation. Cumulative energy demand is the sum of all energy sources drawn directly from the earth, such as natural gas, oil, coal, biomass, or hydropower energy. The total primary energy contains further categories, namely non-renewable and renewable energy, and feedstock energy.

5.3 Allocation and Assumptions

Life cycle analysis requires that assumptions are made to constrain the project boundary or model processes when little to no data are available. In this study of calcium carbonate, the following assumptions were made:

- Off-spec and other materials are disposed of in an inert landfill unless otherwise specified.
- There are no significant air emissions from the production process other than particulates. Combustion emissions are assumed through secondary processes used from the US LCI database.
- When a material is not available in the available LCI databases, another chemical, which has similar manufacturing and environmental impacts, may be used as a proxy, representing the actual chemical. The Proxy Chemical List used in this analysis includes:
  - Stearic Acid- Fatty acids from palm oil and fatty alcohol sulfate from palm oil
  - Biocides- Biocides for paper production (cyanazine, dithiocarbamate compounds, chlorine dioxide, and hydrogen peroxide,
  - Dispersant- Polycarboxylates
  - Heat Transfer Fluid- Ethylene glycol
  - Flotation Agent 1- Imidazole and acetic acid
  - Flotation Agent 2- Fatty acids from tallow oil, and EDTA
  - Antifreeze- Ethylene glycol
  - Explosives- Tovex
  - Winterizing Agent- Naphtha and kerosene

    - Suspension aid- Sodium hydroxide and acrylic acid

6.0 Calcium Carbonate LCA Results

This section presents the results of the LCA study. It includes cumulative energy, global warming, and other quantified impacts for each of the TRACI impact categories. The results are relative expressions of possible environmental impacts and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. The coarse, dry 30µg and the fine treated products are focused on for many of these results, as those products present the extremes of impacts. The course, dry 30µg grade typically requires less processing and the fine, treated product requires the most materials and energy inputs. Section 6.4 discusses the impacts of each product, however, through the cradle-to-gate system boundaries.

A manufacturer chooses the raw materials and processes that will be used to produce a product, but their ability to directly influence the processing, and thus environmental impact, of raw materials is typically outside of the manufacturer's control. Figure 6-1 below illustrates the total life cycle of a product from raw materials extraction and processing through installation, use and end-of-life. Environmental impacts that occur in raw material shipping, manufacturing, and final product shipping are directly under the participating companies' control. This puts much of the environmental impact of the final product out of the control of their control as well, unless material substitutions can be made.

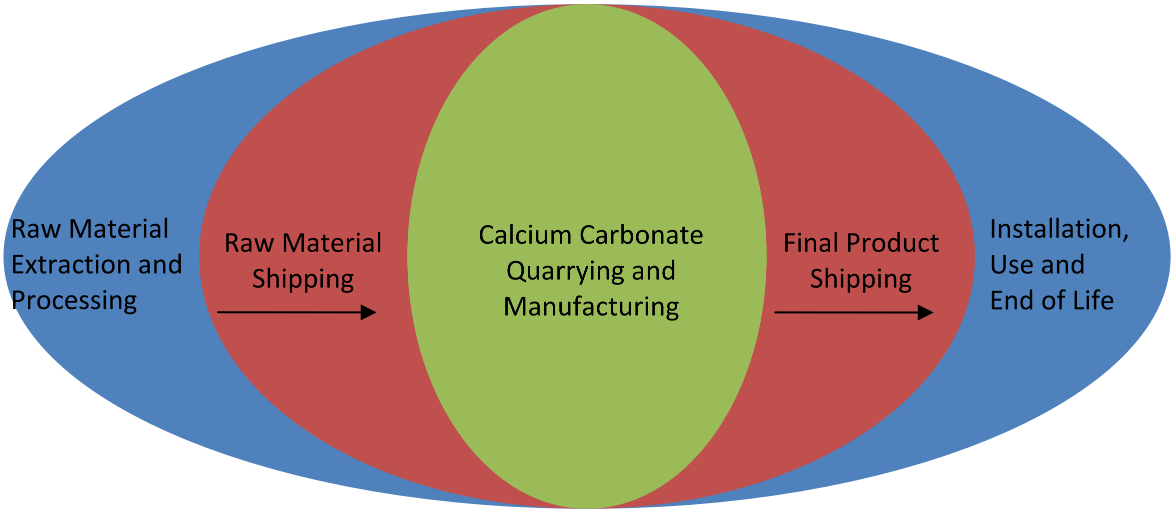

Figure 6.1 - Life Cycle Stage Control Diagram

6.1 Quarry Impacts

6.1.1 Quarrying Energy and Carbon Analysis

Energy is required to extract and crush the calcium carbonate before it is sent to the plants. Table 6.1, below, lists the cumulative energy consumed and global warming potential for the quarry extraction of the limestone. These results are based on the quarry inventory in Section 4.2 where allocation and fuels and energy sources are discussed.

Table 6.1 - Energy Use During the Manufacturing and Shipping Processes

Quarry Energy Consumption (per short ton of rock)	Cumulative Energy Demand (MJ)	Global Warming Potential (kg CO_2 eq)
Electricity	3.11E+01	2.19E+00
Gasoline	5.03E-01	3.06E-02
Diesel	5.42E+01	3.70E+00
Waste Fuel Oil	4.95E-03	5.19E-01
Total	8.58E+01	6.44E+00

The figures below show the energy and global warming potential data from Table 6.1 in pie charts. This illustrates that diesel fuel has the highest contribution to energy used to produce calcium carbonate in the quarries.

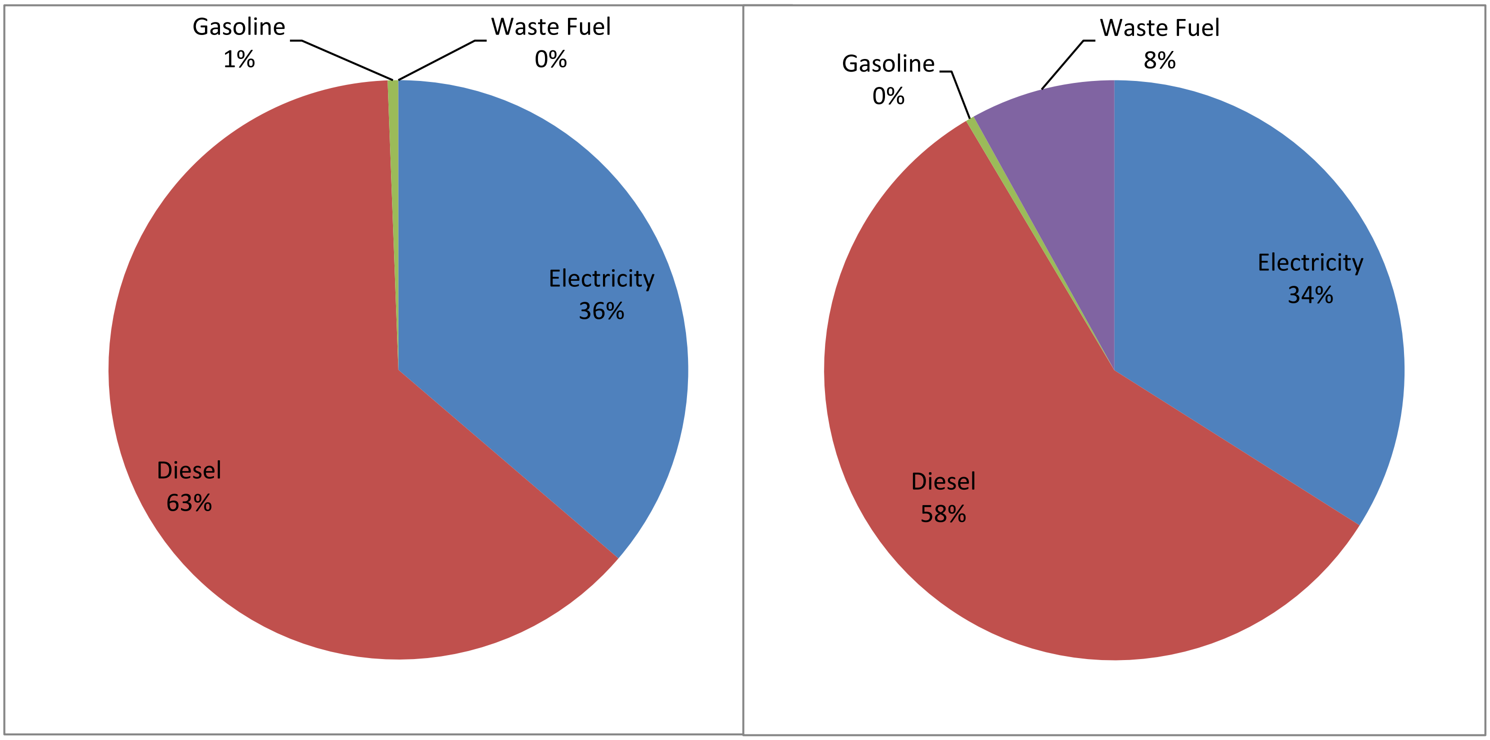

Figure 6.2 - CED (left) and GWP (right) to Extract Calcium Carbonate in the Quarry

6.1.2 Additional Environmental Impacts from Quarry Processing

Besides energy demand and carbon emissions, there are other impacts to be considered for quarry operations. A TRACI analysis was run for this phase to capture these impacts. Waste was also considered within these categories. Table 6.2 and Figure 6.3 show the overall impacts of the quarry processing of calcium carbonate.

Table 6.2 - TRACI Analysis of Quarry Processing (per dry ton of product)

Impact category	Unit	Electricity	Diesel	Gasoline	Waste Fuel	Waste	Total
Global Warming	kg CO_2 eq	2.19E+00	3.70E+00	3.06E-02	5.19E-01	8.47E-04	6.44E+00
Fossil Fuel Depletion	MJ surplus	1.48E+00	7.16E+00	6.64E-02	6.55E-04	1.72E-03	8.71E+00
Eutrophication	kg N eq	2.59E-04	3.04E-03	2.09E-05	3.62E-04	4.65E-07	3.68E-03
Smog	kg O_3 eq	1.34E-01	1.61E+00	1.09E-02	2.05E-01	1.43E-04	1.96E+00
Acidification	kg SO_2 eq	1.91E-02	5.08E-02	3.55E-04	5.84E-03	5.23E-06	7.61E-02
Ozone Depletion	kg CFC_{-11} eq	3.59E-11	1.52E-10	1.41E-12	1.39E-14	6.18E-11	2.51E-10
Carcinogenics	CTU_h	3.70E-09	5.48E-08	5.08E-10	6.91E-11	1.59E-11	5.90E-08
Non-carcinogenics	CTU_h	6.74E-08	5.26E-07	4.88E-09	2.98E-10	1.18E-10	5.98E-07
Respiratory Effects	kg $PM_{2.5}$ eq	9.50E-04	1.05E-03	5.70E-06	8.55E-05	4.12E-04	2.50E-03
Ecotoxicity	CTU_E	8.80E-01	1.01E+01	9.41E-02	1.10E-03	2.93E-03	1.11E+01
Cumulative Energy Demand	MJ	3.11E+01	5.42E+01	5.03E-01	4.95E-03	1.32E-02	8.59E+01

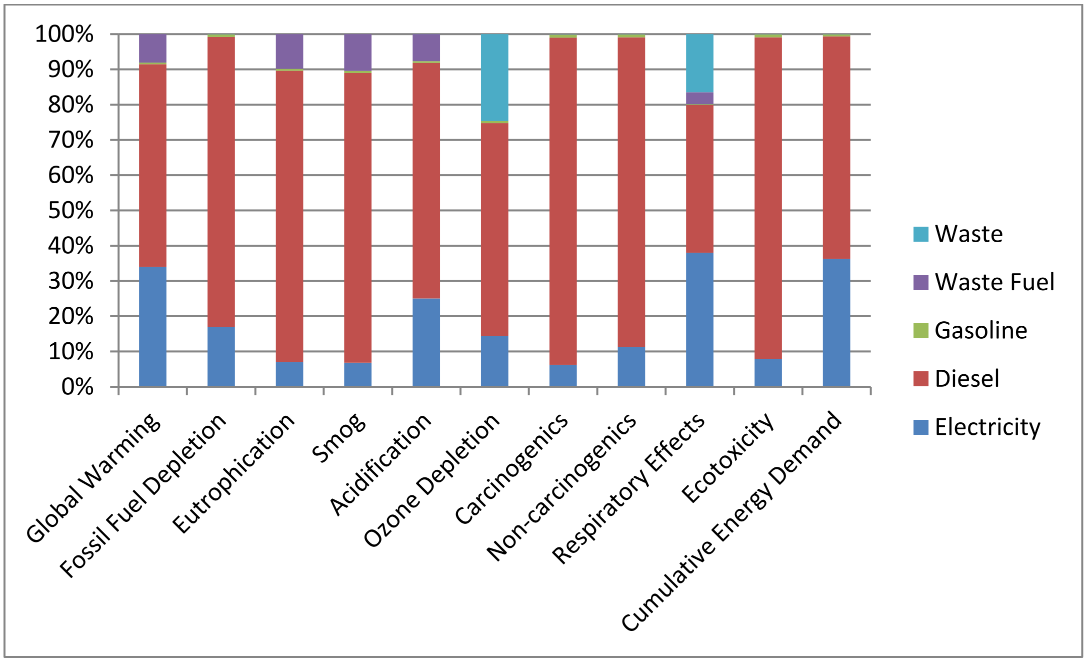

Figure 6.3 - TRACI analysis of Quarry Processing (per dry ton of product)

As shown in the figure above, the quarry processing impacts are primarily driven by diesel use. This is due to the emissions associated with combusting diesel and the use of crude oil to create diesel at a refinery.

6.1.3 Plant Energy and Carbon Analysis

Energy is required to process the materials delivered from the quarry to transform them into the final products.

Table 6.3 below lists the amount of cumulative energy consumed for these steps, which involves processes most directly under the control of the participating IMA-NA members. All of the energy consumption was converted to megajoules (MJ) to allow for comparison of energy consumption across all uses. This energy consumption is based on the original plant inventory in Section 4.2 where allocation and fuels and energy sources are discussed.

Table 6.3 - Energy Use During the Product Plant Processing (MJ/ dry ton of product)

Plant Energy Consumption	Screened	Coarse 30µg	Coarse 20µg	Fine Slurry 3µg	Fine Treated 3µg
Electricity	1.57E+02	2.35E+02	3.60E+02	2.10E+03	2.97E+03
Natural Gas	2.00E-01	1.59E-02	9.82E-03	9.29E-04	1.17E+00
Propane	-	8.84E+00	-	-	-
Waste	5.00E-03	1.03E-03	1.95E-03	1.97E+00	4.30E+00
Total	1.57E+02	2.43E+02	3.60E+02	2.10E+03	3.0E+03
Raw Materials Transportation	Screened	Coarse 30µg	Coarse 20µg	Fine Slurry 3µg	Fine Treated 3µg
Truck	2.62E+00	7.45E+01	5.95E+01	1.63E+01	2.89E+01
Barge	-	-	1.05E+02	1.20E+02	1.17E+02
Rail	-	-	6.75E+01	7.72E+01	6.42E+01
Total	2.62E+00	7.45E+01	2.32E+02	2.14E+02	2.11E+02

Figure 6.4 illustrates the energy breakdown for two of the products (coarse dry 30µg and fine treated 3µg). This further illustrates the overwhelming contribution of electricity to produce all products.

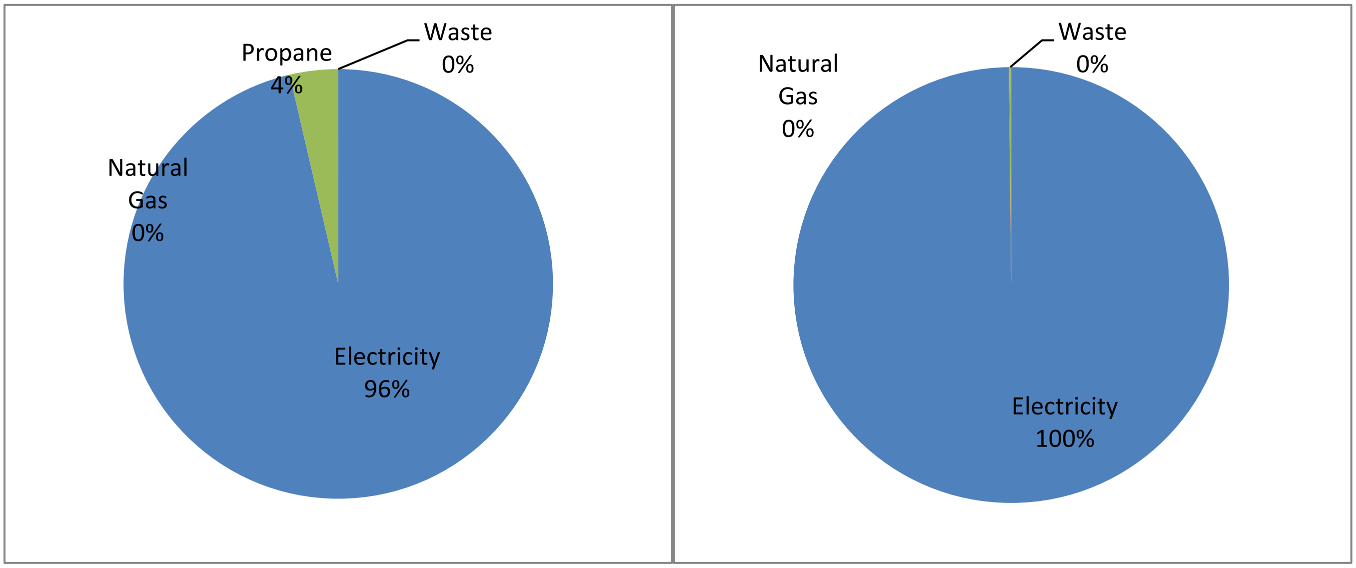

Figure 6.4 - Energy Used to Manufacture the Coarse Dry 30µg (left) and Fine Treated 3µg (right) Products

Electricity drives cumulative energy demand, while propane usage and manufacturing waste only have small impacts of the manufacturing of the two calcium carbonate products. Waste quantities increase as processing increases to produce smaller particle sizes of calcium carbonate. This trend is due to additional materials required such as more grinding media, filters, and the increase for scrap or reject product that may not be down-cycled into lower grade products. The drying of the treated product also requires heating fluids and stearic acid, some of which may have the potential to be evaporated or generated scraps or wastes based on processing.

Table 6.4, displays the breakdown of global warming potential (GWP) from the manufacturing of all of the calcium carbonate products. Similar to energy use, the majority of GWP in the plant processing is from electricity consumption.

Table 6.4 - GWP from the Plant Processing (kg CO_2 eq/dry ton product)

Plant Processing Global Warming Potential	Screened	Coarse 30µg	Coarse 20µg	Fine Slurry 3µg	Fine Treated 3µg
Electricity	1.10E+01	1.65E+01	2.53E+01	1.47E+02	2.08E+02
Natural Gas	1.14E-02	9.01E-04	5.59E-04	5.28E-05	6.64E-02
Propane		6.22E-01			
Waste	2.80E-04	7.60E-05	1.43E-04	7.53E-02	1.64E-01
Total	1.10E+01	1.71E+01	2.53E+01	1.47E+02	2.09E+02
Raw Materials Transportation	Screened	Coarse 30µg	Coarse 20µg	Fine Slurry 3µg	Fine Treated 3µg
Truck	1.93E-01	5.48E+00	4.37E+00	1.20E+00	2.12E+00
Barge	-	-	7.66E+00	7.66E+00	7.66E+00
Rail	-	-	4.94E+00	5.65E+00	4.94E+00
Total	1.93E-01	5.48E+00	1.70E+01	1.45E+01	1.47E+01

Figure 6.5 shows the global warming breakdown for two of the products. This further illustrates the overwhelming contribution of electricity to GWP from the production of calcium carbonate.

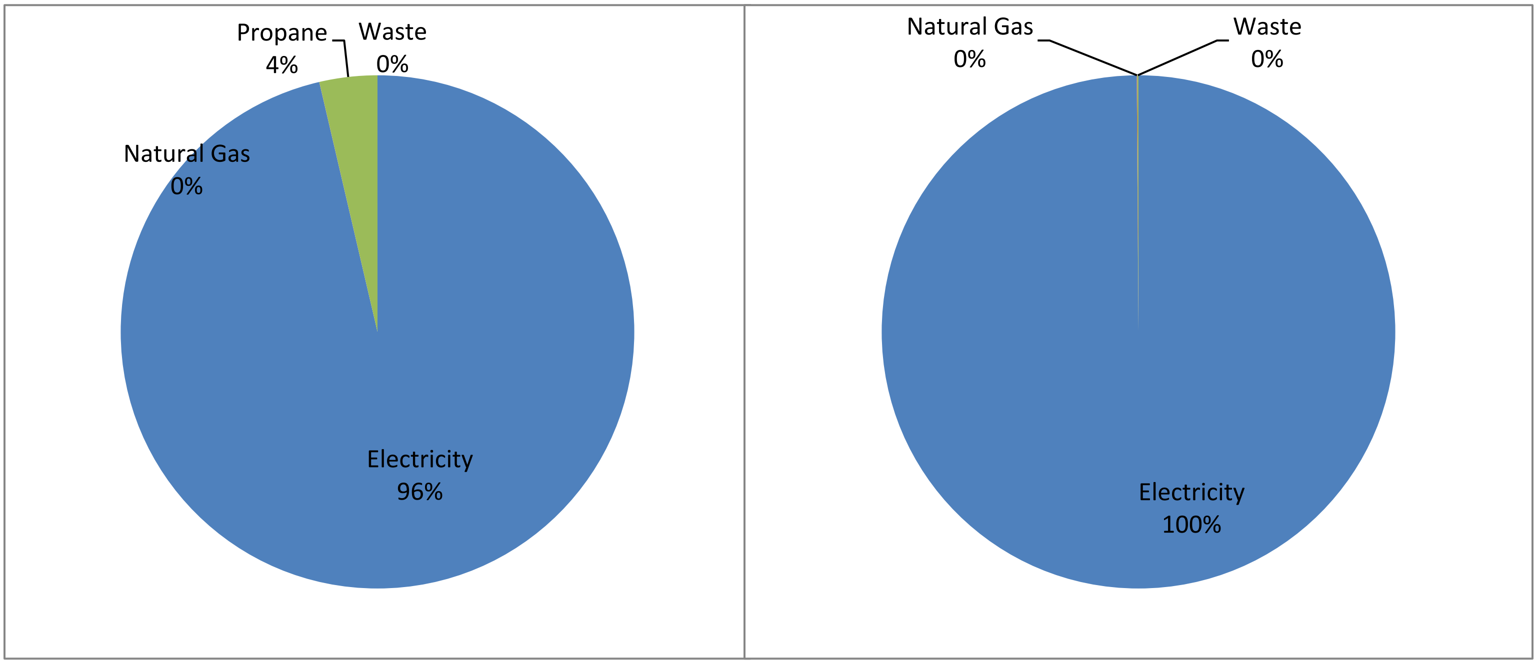

Figure 6.5 - Global Warming Potential in the Manufacture of the Coarse Dry 30µg (left) and Fine Treated 3µg (right) Products

6.1.4 Additional Environmental Impacts from Plant Processing

Besides energy demand and carbon emissions, there are other impacts that can be analyzed through a life cycle analysis. Table 6.5 and Figure 6.6 below show the overall trends of the facilities' processing of all the calcium carbonate products.

Table 6.5 - Calcium Carbonate Product Processing Phase Comparison (per dry ton of product)

Impact Category	Unit	Screened Grade	Coarse Dry 30µg	Coarse Dry 20µg	Fine Slurry 3µg	Fine Treated 3µg
Global Warming	kg CO_2 eq	1.10E+01	1.71E+01	2.53E+01	1.47E+02	2.09E+02
Fossil Fuel Depletion	MJ surplus	7.49E+00	1.23E+01	1.71E+01	9.99E+01	1.4E+02
Eutrophication	kg N eq	1.31E-03	2.04E-03	3.00E-03	1.76E-02	2.5E-02
Smog	kg O_3 eq	6.77E-01	1.04E+00	1.55E+00	9.06E+00	1.3E+01
Acidification	kg SO_2 eq	9.61E-02	1.45E-01	2.20E-01	1.28E+00	1.8E+00
Ozone Depletion	kg CFC_{-11} eq	2.19E-10	2.97E-10	4.18E-10	3.01E-08	6.4E-08
Carcinogenics	CTU_h	1.87E-08	3.67E-08	4.28E-08	2.52E-07	3.6E-07
Non-carcinogenics	CTU_h	3.40E-07	5.93E-07	7.80E-07	4.55E-06	6.4E-06
Respiratory Effects	kg $PM_{2.5}$ eq	5.34E-03	7.22E-03	1.10E-02	6.43E-02	9.1E-02
Ecotoxicity	CTU_E	4.45E+00	8.29E+00	1.02E+01	5.95E+01	8.4E+01
Cumulative Energy Demand	MJ	1.57E+02	2.43E+02	3.60E+02	2.10E+03	3.0E+03

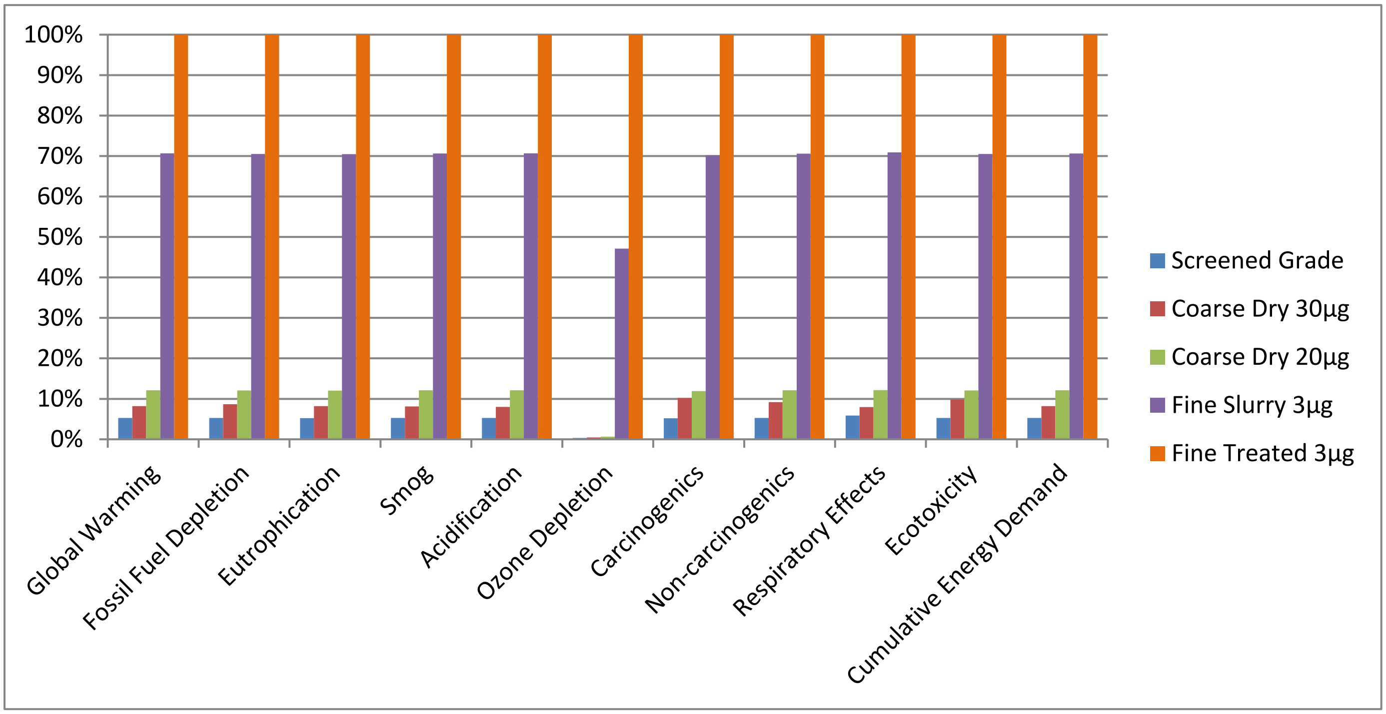

Figure 6.6 - Calcium Carbonate Product Processing Phase Comparison

The screened grade has the lowest environmental impacts during the processing stage of the five products in most of the impact categories. The ozone depletion impacts of the screened and coarse grade products are lower because of the smaller amount of materials being sent to the landfill.

Fine grade products require significantly more energy and material inputs during processing which increase the associated environmental impacts of the production stage.

6.2 Support Material Impacts

6.2.1 Quarry Support Materials

Table 6.6 and Figure 6.7 below show the potential environmental impacts of the support materials used in the quarries during the exaction of the rock.

Table 6.6 - Support Material Impacts for Quarry (per dry ton of product)

Impact category	Unit	Antifreeze	Explosives	Truck Battery	Truck Filter	Truck Tire	Winterizing Agent	Oil & Grease	Total
Global Warming	kg CO_2 eq	1.57E-02	1.49E+00	7.57E-04	9.69E-02	3.62E-02	1.32E-02	5.87E-02	1.71E+00
Fossil Fuel Depletion	MJ surplus	4.98E-02	1.46E+00	6.64E-04	4.98E-02	1.14E-01	1.57E-01	4.97E-01	2.33E+00
Eutrophication	kg N eq	3.34E-05	1.51E-02	5.26E-06	3.19E-04	8.62E-06	2.37E-05	2.19E-04	1.57E-02
Smog	kg O_3 eq	6.80E-04	4.68E+00	7.72E-05	6.58E-03	1.77E-03	1.07E-03	3.96E-03	4.69E+00
Acidification	kg SO_2 eq	6.93E-05	1.98E-01	1.96E-05	7.89E-04	1.76E-04	7.93E-05	5.11E-04	2.00E-01
Ozone Depletion	kg CFC_{-11} eq	3.68E-10	1.20E-07	5.47E-11	3.72E-09	9.46E-11	1.90E-08	4.22E-08	1.86E-07
Carcinogenics	CTU_h	7.35E-10	1.40E-07	1.15E-10	3.03E-08	1.01E-09	3.72E-10	3.27E-09	1.76E-07
Non-carcinogenics	CTU_h	3.07E-09	3.41E-07	3.15E-09	3.69E-08	4.85E-10	1.28E-09	1.29E-08	3.99E-07
Respiratory Effects	kg $PM_{2.5}$ eq	5.09E-06	7.34E-03	1.33E-06	1.37E-04	1.25E-05	6.09E-06	3.96E-05	7.54E-03
Ecotoxicity	CTU_E	7.71E-02	9.23E+00	2.60E-02	1.14E+00	6.16E-02	2.22E-02	2.75E-01	1.08E+01
Cumulative Energy Demand	MJ	4.65E-01	1.70E+01	1.05E-02	1.27E+00	9.21E-01	1.19E+00	3.96E+00	2.48E+01

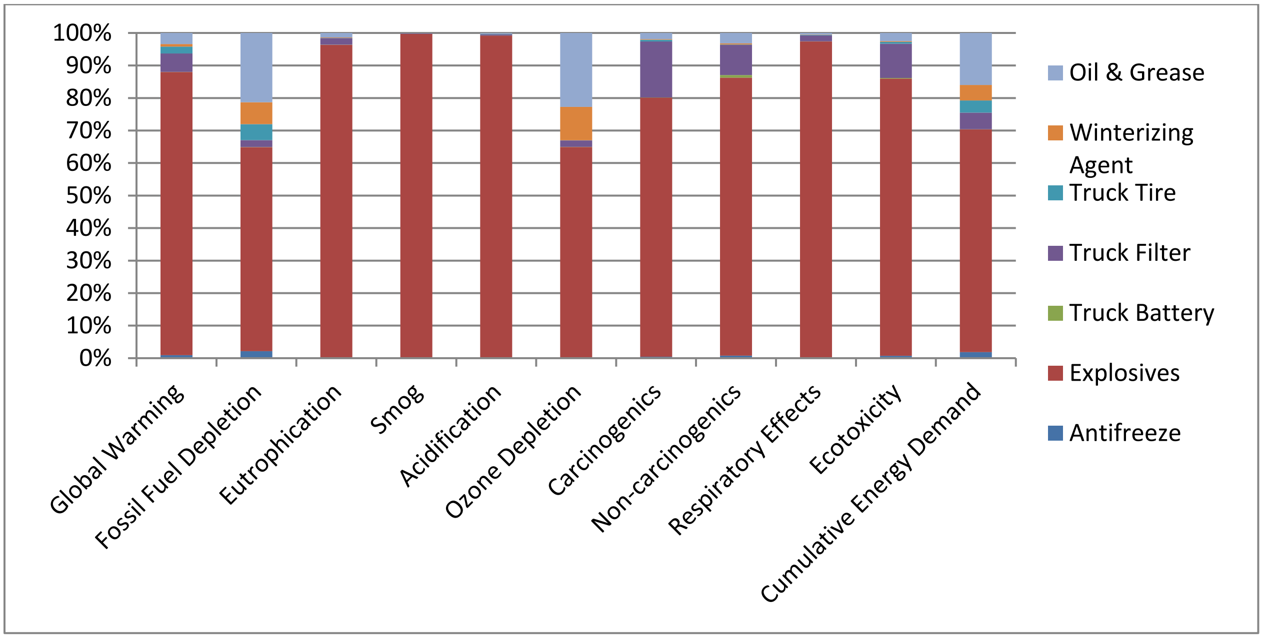

Figure 6.7 - Support Material Impacts for Quarry

Based on the results, the explosives contribute the most to all of the impact categories. A further analysis was done to determine if most of the explosives impacts were due to the blasting emissions, or from manufacturing the explosives. The results are shown below.

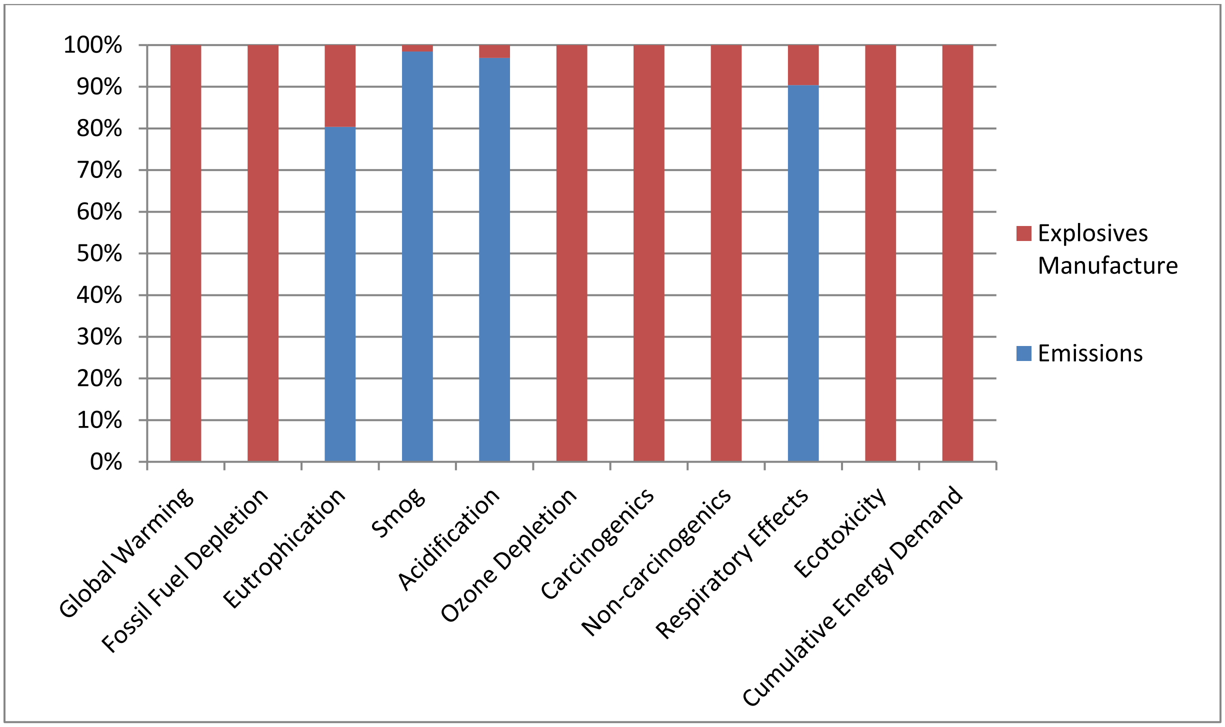

Figure 6.8 - Quarry Explosives Impact Distribution

As shown in Figure 6.8 above, the explosives manufacture has the highest impacts in most of the impact categories such as global warming and fossil fuel depletion.

6.2.2 Plant Production Support Materials

Table 6.7 and Figure 6.9 below show the impacts of the upstream environmental impacts from producing the support materials for the coarse dry 30µg.

Table 6.7 - Support Material Impacts for Coarse Dry 30µg (per dry ton of product)

Impact category	Unit	Steel Screen	Conveyor Belt	Total
Global Warming	kg CO_2 eq	1.01E-02	1.92E-02	2.93E-02
Fossil Fuel Depletion	MJ surplus	8.00E-03	6.54E-02	7.34E-02
Eutrophication	kg N eq	3.27E-05	3.92E-05	7.20E-05
Smog	kg O_3 eq	6.21E-04	8.89E-04	1.51E-03
Acidification	kg SO_2 eq	6.05E-05	9.34E-05	1.54E-04
Ozone Depletion	kg CFC_{-11} eq	6.02E-10	5.43E-09	6.03E-09
Carcinogenics	CTU_h	8.09E-09	8.37E-10	8.92E-09
Non-carcinogenics	CTU_h	6.98E-09	3.53E-09	1.05E-08
Respiratory Effects	kg $PM_{2.5}$ eq	2.47E-05	9.25E-06	3.40E-05
Ecotoxicity	CTU_E	2.27E-01	8.66E-02	3.13E-01
Cumulative Energy Demand	MJ	1.60E-01	5.94E-01	7.54E-01

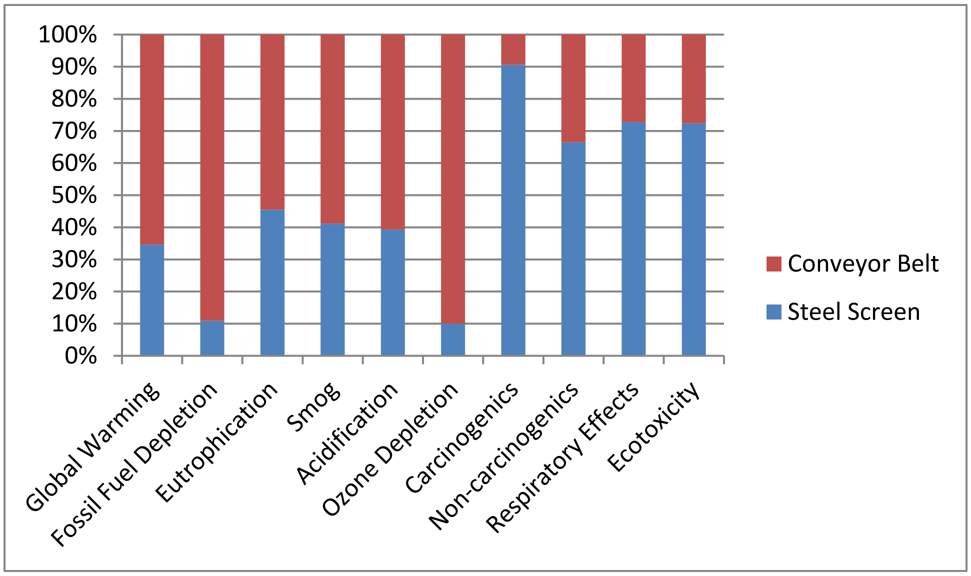

Figure 6.9 - Support Material Impacts for Coarse Dry 30µg

The results in Table 6.7 and Figure 6.9 reveal that the conveyor belt has the largest impact in most of the environmental categories. (The belts must be replaced with regular maintenance and the average replacement rate for 2014 was modeled and is represented above.) Steel production for the screened grade drives health impacts for carcinogenics, non-carcinogenics, respiratory effects and ecotoxicity.

The upstream environmental impacts from producing the support materials for the fine treated 3µg products are shown in Table 6.8 and Figure 6.10 below.

Table 6.8 - Support Material Impacts for Fine Treated 3µg (per dry ton of product)

Impact category	Global Warming	Fossil Fuel Depletion	Eutrophi-cation	Smog	Acidifi-cation	Ozone Depletion	Carcinogenics	Non-carcinogenics	Respiratory Effects	Ecotoxicity	Cumulative Energy Demand
Unit	kg CO_2 eq	MJ surplus	kg N eq	kg O_3 eq	kg SO_2 eq	kg CFC_{-11} eq	CTU_h	CTU_h	kg $PM_{2.5}$ eq	CTU_E	MJ
Shaker Screen (Steel)	3.2E-04	2.5E-04	1.0E-06	2.0E-05	1.9E-06	1.9E-11	2.5E-10	2.2E-10	7.8E-07	7.1E-03	5.0E-03
Conveyor Belt	1.3E-02	4.5E-02	2.7E-05	6.1E-04	6.4E-05	3.7E-09	5.8E-10	2.4E-09	6.4E-06	6.0E-02	4.1E-01
Biocides	1.7E-01	2.0E-01	5.9E-04	8.1E-03	1.9E-03	2.6E-08	1.5E-08	1.8E-07	1.2E-04	4.2E+00	2.9E+00
Urethane Screen	5.2E-03	1.4E-02	2.7E-06	2.8E-04	3.3E-05	2.0E-10	1.8E-10	6.9E-10	2.2E-06	2.1E-02	1.2E-01
Water	4.8E-02	2.9E-02	1.7E-04	2.5E-03	3.0E-04	2.4E-09	5.3E-09	1.5E-08	2.3E-05	3.3E-01	7.6E-01
Flotation Agent 1	1.4E+00	3.7E+00	5.5E-03	6.4E-02	7.2E-03	1.6E-07	7.4E-08	2.8E-07	1.0E-03	1.1E+01	3.4E+01
Flotation Agent 2	1.5E+00	2.6E+00	4.9E-03	5.7E-02	5.7E-03	1.7E-07	7.5E-08	3.4E-07	4.2E-04	6.7E+00	2.6E+01
Dispersant	3.6E+00	1.0E+01	1.1E-02	1.2E-01	1.1E-02	2.5E-07	2.2E-07	1.0E-06	1.1E-03	2.2E+01	9.3E+01
Grinding Media 2	1.5E-01	1.2E-01	4.0E-04	1.3E-02	1.0E-03	9.3E-09	6.4E-09	2.2E-08	1.0E-04	5.1E-01	2.1E+00
Stearic Acid	2.7E+01	2.0E+01	9.8E-02	1.9E+00	1.7E-01	1.5E-06	1.1E-06	6.1E-07	4.7E-02	1.2E+02	8.6E+02
Grinding Media 1	3.2E-01	6.0E-01	8.8E-05	4.2E-02	2.9E-03	2.9E-09	2.7E-09	3.5E-08	1.1E-04	5.7E-01	4.8E+00
Suspension Aid	3.1E-02	8.2E-02	5.4E-05	1.1E-03	1.2E-04	7.4E-10	1.2E-09	4.5E-09	8.4E-06	1.1E-01	7.7E-01
Filter (plastic bag)	4.9E-02	1.4E-01	1.0E-04	2.1E-03	2.2E-04	2.7E-09	3.1E-09	1.0E-08	1.8E-05	2.8E-01	1.3E+00
Heat Transfer Fluid	9.8E-03	3.4E-02	2.7E-05	4.4E-04	3.9E-05	7.7E-10	4.6E-10	2.2E-09	7.3E-06	8.2E-02	3.2E-01
Filter (Socks)	9.6E-04	4.5E-03	3.6E-07	4.0E-05	3.0E-06	3.4E-13	2.5E-11	1.2E-11	2.3E-07	1.5E-03	3.6E-02
Total	3.4E+01	3.7E+01	1.2E-01	2.2E+00	2.0E-01	2.2E-06	1.5E-06	2.5E-06	5.0E-02	1.7E+02	1.0E+03

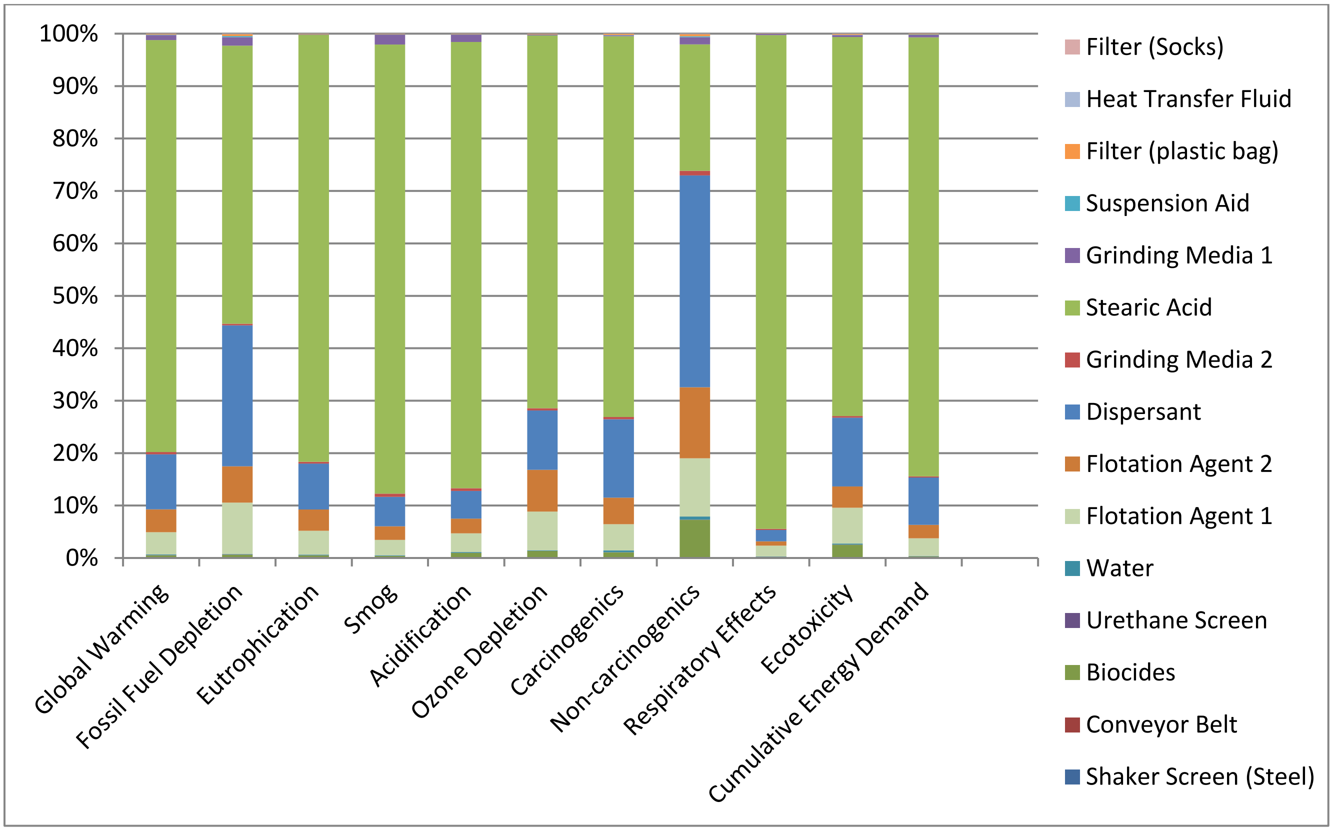

Figure 6.10 - Support Material Impacts for Fine Treated 3µg

The results show the overwhelming impact stearic acid has on most of the impact categories. The dispersant has the second largest impact.

6.3 Overall Environmental Impact

6.3.1 Overall Energy and Carbon Life Cycle Impacts

Energy is consumed in raw materials extraction, processing, transportation, and the waste disposal phases. The cumulative energy demand (CED) represents all the energy needed to convert a material to its final product. The values for cumulative energy demand for all the calcium carbonate products studied are listed in Table 6.9 and illustrated in Figure 6.11.

Table 6.9 - Cumulative Energy Demand (CED) for Calcium Carbonate Products (MJ/dry ton of product)

Overall Energy Consumption	Screened	Coarse 30µg	Coarse 20µg	Fine Slurry 3µg	Fine Treated 3µg
Quarry Operations	1.50E+02	1.15E+02	1.33E+02	1.56E+02	1.53E+02
Support Materials	1.74E+00	7.54E-01	1.33E+00	1.94E+02	1.03E+03
Support Materials Transportation	2.62E+00	7.45E+01	2.32E+02	2.14E+02	2.11E+02
Processing	1.57E+02	2.43E+02	3.60E+02	2.10E+03	2.97E+03
Manufacturing Waste	5.00E-03	1.03E-03	1.95E-03	1.97E+00	4.30E+00

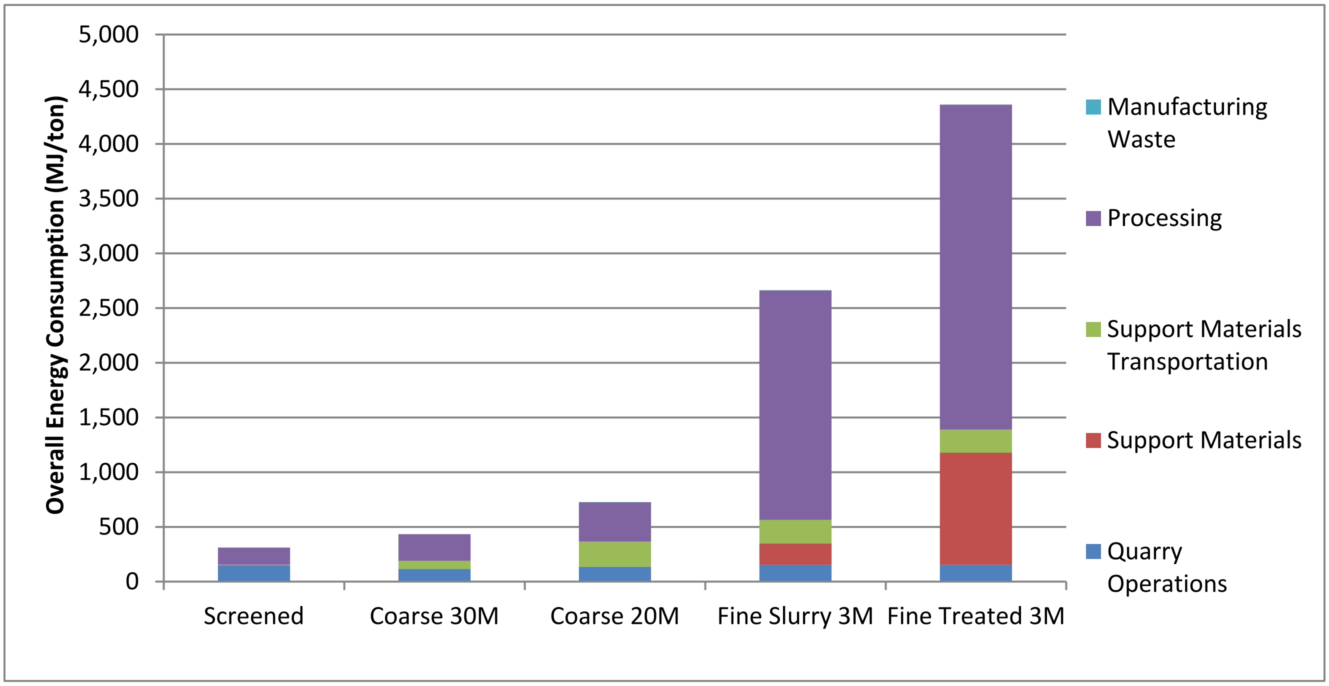

Figure 6.11 - Cumulative Energy Demand (CED) for the Various Life Cycle Stages of Calcium Carbonate (MJ/ton)

Global warming potential (GWP) was also analyzed for the same life cycle stages. The GWP results represent all the greenhouse gas emissions created in the extraction and conversion of the various raw materials through the waste disposal. The values for GWP for one ton of the calcium carbonate products are listed in Table 6.10 and illustrated in Figure 6.12.

Table 6.10 - Global Warming Potential (GWP) Values for Calcium Carbonate Products (kg CO_2 eq/dry ton of product)

Global Warming Potential	Screened	Coarse 30µg	Coarse 20µg	Fine Slurry	Fine Treated 3µg
Quarry Operations	1.11E+01	8.45E+00	9.82E+00	1.15E+01	1.13E+01
Support Materials	8.63E-02	2.93E-02	6.97E-02	8.41E+00	3.40E+01
Support Materials Transportation	1.93E-01	5.48E+00	1.70E+01	1.56E+01	1.54E+01
Processing	1.10E+01	1.71E+01	2.53E+01	1.47E+02	2.09E+02
Manufacturing Waste	2.80E-04	7.60E-05	1.43E-04	7.53E-02	1.64E-01

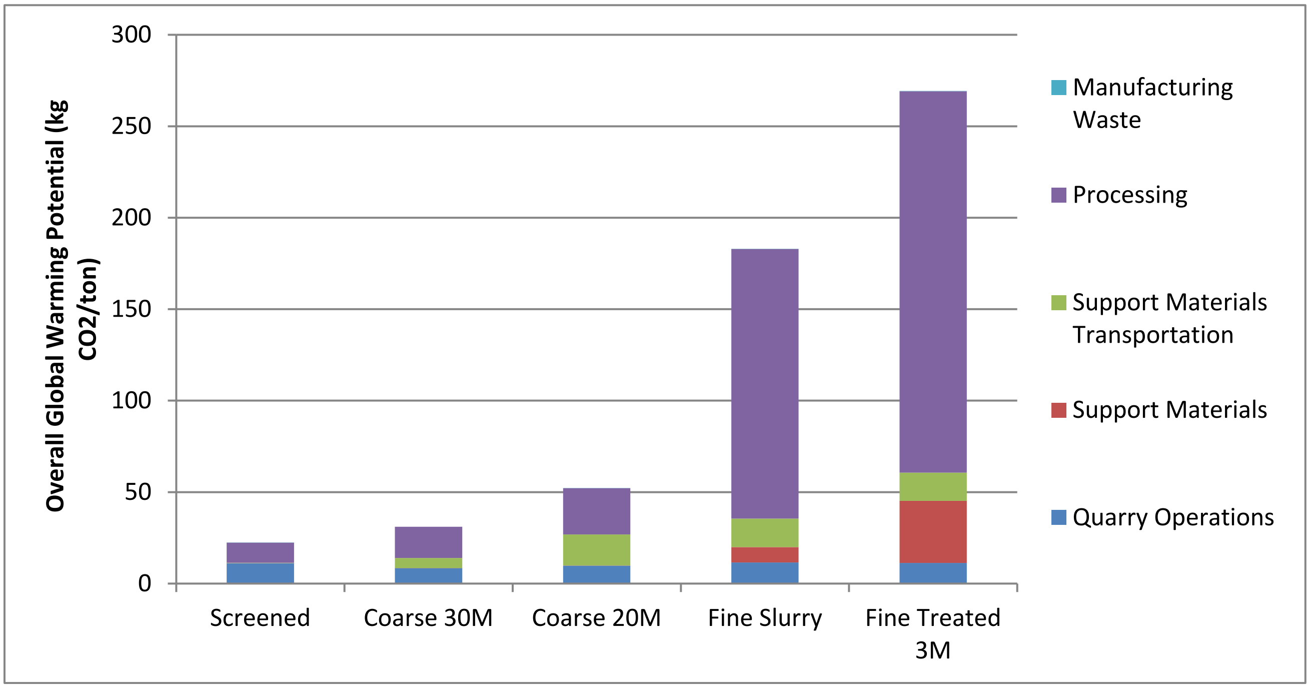

Figure 6.12 - Global Warming Potential (GWP) for the Various Life Cycle Stages of Calcium Carbonate (kg CO_2 eq/ton product)

As expected, the fine products have much larger impacts than the screened and coarse products. For both GWP and CED, the processing phase has the largest impact for all products excluding the screened grade. For screened grade, the quarry operations and processing stages are evenly matched because this product does not go through significant processing after leaving the quarry.

6.3.2 Overall Environmental Impacts using TRACI

The graphs in this section are designed to communicate the overall environmental impacts of the calcium carbonate products using the TRACI methodology. For more details on the impact categories, see Section 5.2 above.

Coarse, Dry 30µg Product

Table 6.11 and Figure 6.13 demonstrate the overall environmental impact (using the TRACI methodology) of processing one ton of the coarse dry 30 micron product. The figure illustrates the relative impact contribution from each of the life cycle stages analyzed (Quarry Operations, Support Material Extraction, Support Materials Transportation, Processing, and Manufacturing Waste) to each of the environmental impacts. In this analysis, support material transportation impacts are separated from the support material extraction and processing stage.

Table 6.11 - Environmental Impacts of Coarse Dry 30µg Calcium Carbonate (per dry ton of product) (TRACI Impact Assessment Methodology)

Impact Category	Unit	Quarry Operations	Support Materials	Support Materials Transportation	Processing	Manufacturing Waste	Total
Global Warming	kg CO_2 eq	8.45E+00	2.93E-02	5.48E+00	1.71E+01	7.60E-05	3.11E+01
Fossil Fuel Depletion	MJ surplus	1.14E+01	7.34E-02	9.81E+00	1.23E+01	1.36E-04	3.36E+01
Eutrophication	kg N eq	2.01E-02	7.20E-05	2.25E-03	2.04E-03	3.12E-08	2.45E-02
Smog	kg O_3 eq	6.89E+00	1.51E-03	8.86E-01	1.04E+00	1.23E-05	8.83E+00
Acidification	kg SO_2 eq	2.86E-01	1.54E-04	3.24E-02	1.45E-01	4.50E-07	4.64E-01
Ozone Depletion	kg CFC_{-11} eq	1.92E-07	6.03E-09	8.98E-08	2.95E-10	1.25E-12	2.89E-07
Carcinogenics	CTU_h	2.44E-07	8.92E-09	7.92E-08	3.67E-08	1.10E-12	3.68E-07
Non-carcinogenics	CTU_h	1.03E-06	1.05E-08	8.02E-07	5.93E-07	1.11E-11	2.44E-06
Respiratory Effects	kg $PM_{2.5}$ eq	1.04E-02	3.40E-05	5.77E-04	7.19E-03	2.66E-05	1.82E-02
Ecotoxicity	CTU_E	2.27E+01	3.13E-01	2.03E+01	8.29E+00	2.81E-04	5.16E+01
Cumulative Energy Demand	MJ	1.15E+02	7.54E-01	7.45E+01	2.43E+02	1.03E-03	4.33E+02

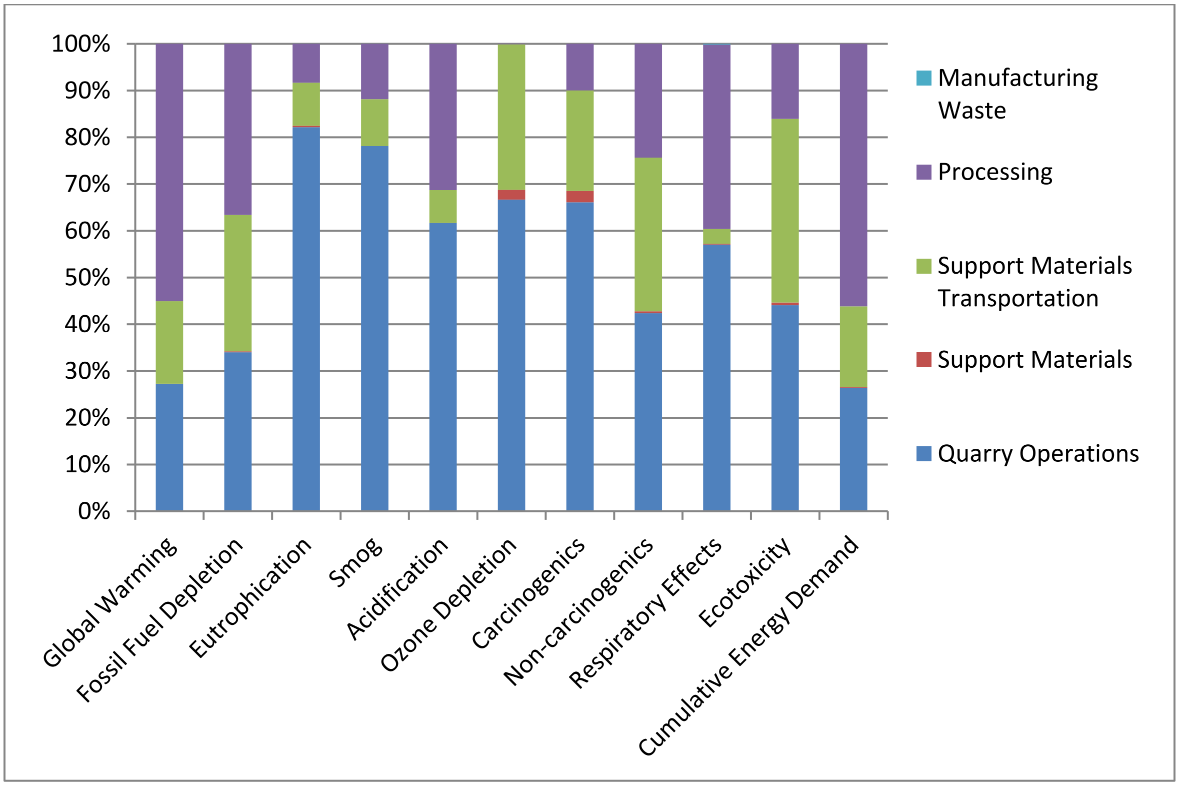

Figure 6.13 - Environmental Impacts of Coarse Dry 30µg Calcium Carbonate (TRACI Impact Assessment Methodology)

The figure above shows that for coarse dry 30µg, processing contributes a majority of the impact in all categories. A significant portion of the processing impact is related to electricity use as shown in Table 6.3 and Figure 6.4.

Fine Treated 3 Micron

Table 6.12 and Figure 6.14 demonstrate the overall environmental impact (using the TRACI methodology) of processing one dry ton of the fine treated 3 micron product.

Table 6.12 - Fine Treated 3µg Environmental Impacts (per dry ton of product) using the TRACI Impact Methodology

Impact Category	Unit	Quarry Operations	Support Materials	Support Materials Transportation	Processing	Manufacturing Waste	Total
Global Warming	kg CO_2 eq	1.13E+01	3.40E+01	1.54E+01	2.09E+02	1.64E-01	2.69E+02
Fossil Fuel Depletion	MJ surplus	1.53E+01	3.74E+01	2.78E+01	1.41E+02	5.43E-01	2.22E+02
Eutrophication	kg N eq	2.69E-02	1.21E-01	1.08E-02	2.47E-02	2.09E-04	1.83E-01
Smog	kg O_3 eq	9.22E+00	2.18E+00	5.60E+00	1.28E+01	3.33E-02	2.98E+01
Acidification	kg SO_2 eq	3.82E-01	2.02E-01	1.79E-01	1.82E+00	1.23E-03	2.58E+00
Ozone Depletion	kg CFC_{-11} eq	2.57E-07	2.18E-06	3.53E-08	3.42E-09	6.05E-08	2.53E-06
Carcinogenics	CTU_h	3.26E-07	1.48E-06	2.13E-07	3.52E-07	6.79E-09	2.38E-06
Non-carcinogenics	CTU_h	1.38E-06	2.54E-06	2.07E-06	6.42E-06	1.67E-08	1.24E-05
Respiratory Effects	kg $PM_{2.5}$ eq	1.39E-02	5.04E-02	3.34E-03	9.05E-02	1.55E-04	1.58E-01
Ecotoxicity	CTU_E	3.04E+01	1.65E+02	4.18E+01	8.40E+01	3.61E-01	3.22E+02
Cumulative Energy Demand	MJ	1.53E+02	1.03E+03	2.11E+02	2.97E+03	4.30E+00	4.36E+03

Figure 6.14 illustrates the relative impact contribution from each of the life cycle stages to each of the environmental impacts. The majority of the impacts in each category are due to either processing or support materials

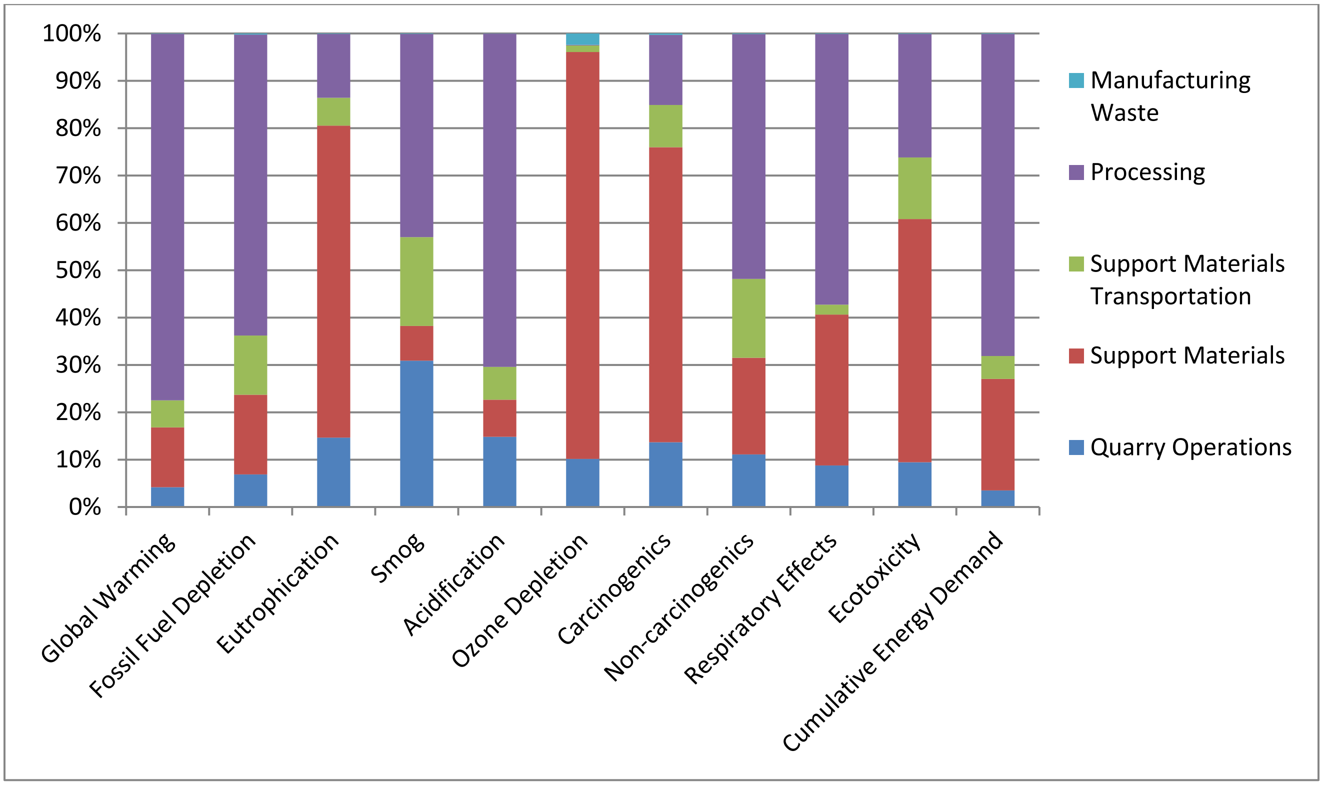

Figure 6.14 - Environmental Impacts of Fine Treated 3µg (TRACI Impact Assessment Methodology)

Below are tables and graphs displaying the overall impacts of the other calcium carbonate products: screened grade, coarse dry 20µg, and fine slurry 3µg.

Screened Grade

Table 6.13 - Overall TRACI Impacts of the Screened Grade Product (per dry ton of product)

Impact Category	Unit	Quarry Operations	Support Materials	Support Materials Transportation	Processing	Manufacturing Waste	Total
Global Warming	kg CO$_2$ eq	1.11E+01	8.63E-02	1.93E-01	1.10E+01	2.80E-04	2.24E+01
Fossil Fuel Depletion	MJ surplus	1.50E+01	1.32E-01	3.45E-01	7.49E+00	6.45E-04	2.29E+01
Eutrophication	kg N eq	2.63E-02	2.50E-04	7.92E-05	1.31E-03	1.97E-07	2.80E-02
Smog	kg O$_3$ eq	9.03E+00	4.92E-03	3.12E-02	6.77E-01	4.92E-05	9.74E+00
Acidification	kg SO$_2$ eq	3.75E-01	4.88E-04	1.14E-03	9.61E-02	1.80E-06	4.72E-01
Ozone Depletion	kg CFC$_{-11}$ eq	2.52E-07	1.06E-08	3.16E-09	1.81E-10	3.80E-11	2.66E-07
Carcinogenics	CTU$_h$	3.19E-07	5.03E-08	2.79E-09	1.87E-08	6.61E-12	3.91E-07
Non-carcinogenics	CTU$_h$	1.35E-06	4.70E-08	2.82E-08	3.40E-07	3.67E-11	1.77E-06
Respiratory Effects	kg PM$_{2.5}$ eq	1.36E-02	1.63E-04	2.03E-05	4.79E-03	5.48E-04	1.91E-02
Ecotoxicity	CTU$_E$	2.98E+01	1.49E+00	7.13E-01	4.45E+00	8.92E-04	3.64E+01
Cumulative Energy Demand	MJ	1.50E+02	1.74E+00	2.62E+00	1.57E+02	5.00E-03	3.12E+02

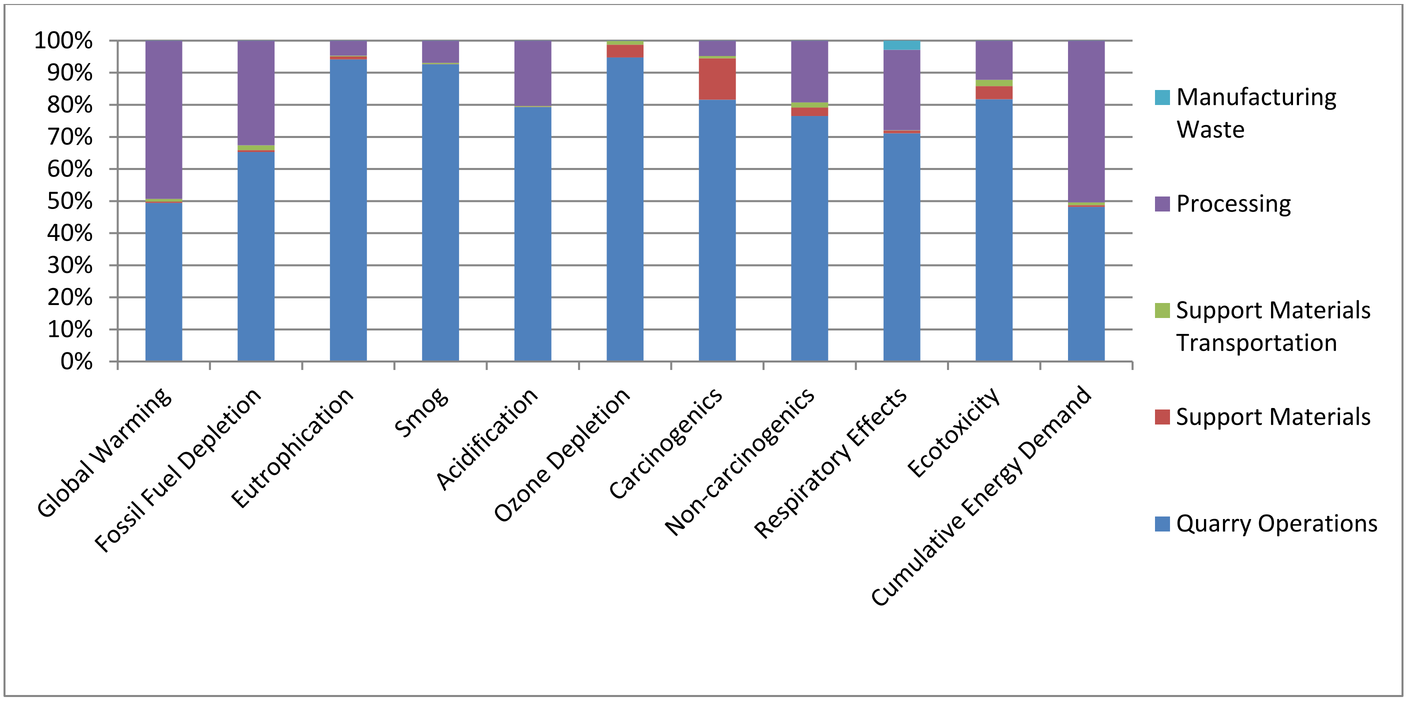

Figure 6.15 - Overall TRACI Impacts of the Screened Grade Product

Coarse, Dry 20µg

Table 6.14 - Overall TRACI Impacts of Coarse Dry 20µg Product (per dry ton of product)

Impact Category	Unit	Quarry Operations	Support Materials	Support Materials Transportation	Processing	Manufacturing Waste	Total
Global Warming	kg CO_2 eq	9.82E+00	6.97E-02	1.70E+01	2.53E+01	1.43E-04	5.22E+01
Fossil Fuel Depletion	MJ surplus	1.33E+01	9.40E-02	3.06E+01	1.71E+01	2.57E-04	6.12E+01
Eutrophication	kg N eq	2.34E-02	2.07E-04	1.15E-02	3.00E-03	5.89E-08	3.81E-02
Smog	kg O_3 eq	8.02E+00	4.04E-03	5.84E+00	1.55E+00	2.32E-05	1.54E+01
Acidification	kg SO_2 eq	3.33E-01	3.99E-04	1.88E-01	2.20E-01	8.49E-07	7.41E-01
Ozone Depletion	kg CFC_{-11} eq	2.24E-07	7.47E-09	7.22E-08	4.16E-10	2.35E-12	3.04E-07
Carcinogenics	CTU_h	2.83E-07	4.43E-08	2.37E-07	4.28E-08	2.07E-12	6.07E-07
Non-carcinogenics	CTU_h	1.20E-06	4.04E-08	2.31E-06	7.80E-07	2.10E-11	4.33E-06
Respiratory Effects	kg $PM_{2.5}$ eq	1.21E-02	1.41E-04	3.49E-03	1.10E-02	2.85E-05	2.67E-02
Ecotoxicity	CTU_E	2.64E+01	1.29E+00	4.85E+01	1.02E+01	5.31E-04	8.64E+01
Cumulative Energy Demand	MJ	1.33E+02	1.33E+00	2.32E+02	3.60E+02	1.95E-03	7.27E+02

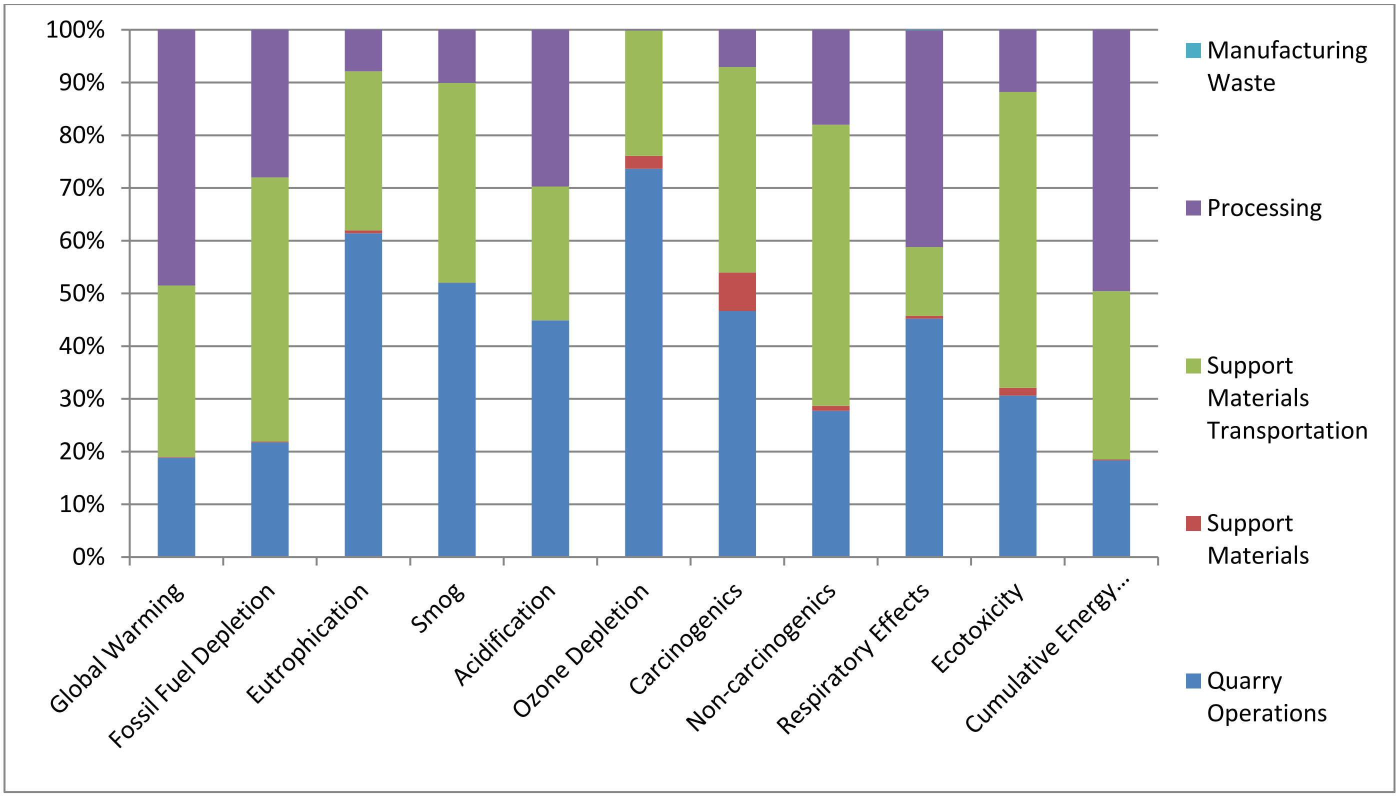

Figure 6.16 - Overall TRACI Impacts of Coarse Dry 20µg Product

Fine Slurry 3µg Product

Table 6.15 - Overall TRACI Impacts of Fine Slurry 3µg Product (per dry ton of product)

Impact Category	Unit	Quarry Operations	Support Materials	Support Materials Transportation	Processing	Manufacturing Waste	Total
Global Warming	kg CO_2 eq	1.15E+01	8.41E+00	1.56E+01	1.47E+02	7.53E-02	1.83E+02
Fossil Fuel Depletion	MJ surplus	1.56E+01	2.04E+01	2.82E+01	9.97E+01	2.49E-01	1.64E+02
Eutrophication	kg N eq	2.74E-02	2.64E-02	1.16E-02	1.75E-02	9.57E-05	8.30E-02
Smog	kg O_3 eq	9.41E+00	3.43E-01	6.06E+00	9.04E+00	1.53E-02	2.49E+01
Acidification	kg SO_2 eq	3.90E-01	3.36E-02	1.92E-01	1.28E+00	5.63E-04	1.90E+00
Ozone Depletion	kg CFC_{-11} eq	2.63E-07	7.41E-07	2.02E-08	2.42E-09	2.77E-08	1.05E-06
Carcinogenics	CTU_h	3.32E-07	4.77E-07	2.15E-07	2.49E-07	3.11E-09	1.28E-06
Non-carcinogenics	CTU_h	1.41E-06	2.27E-06	2.08E-06	4.54E-06	7.67E-09	1.03E-05
Respiratory Effects	kg $PM_{2.5}$ eq	1.42E-02	3.36E-03	3.59E-03	6.40E-02	3.14E-04	8.54E-02
Ecotoxicity	CTU_E	3.10E+01	5.36E+01	4.13E+01	5.93E+01	1.66E-01	1.85E+02
Cumulative Energy Demand	MJ	1.56E+02	1.94E+02	2.14E+02	2.10E+03	1.97E+00	2.66E+03

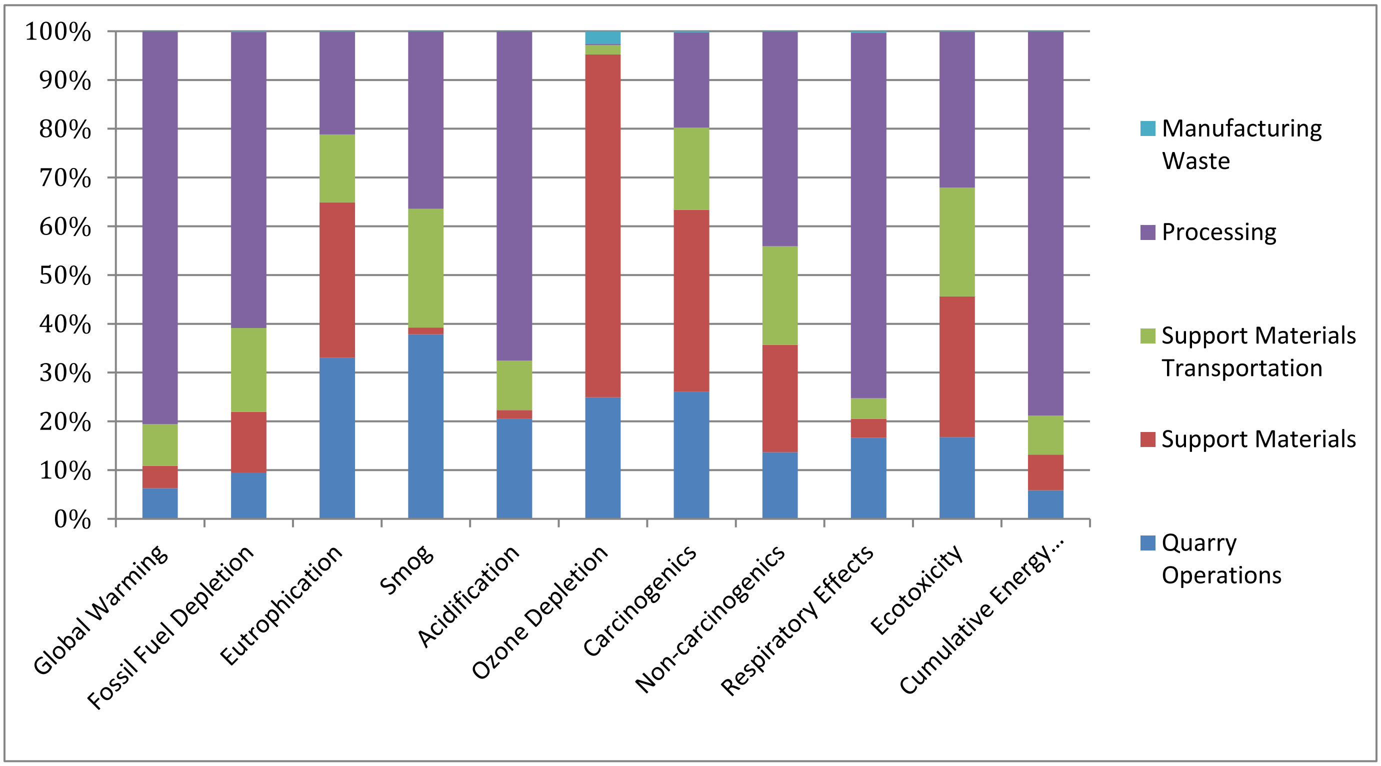

Figure 6.17 - Overall TRACI Impacts of Fine Slurry 3µg Product

6.4 All Calcium Carbonate Products Comparison

A side-by-side comparison showing the environmental impacts of the screened grade, coarse dry 30 micron, coarse dry 20 micron, fine slurry 3 micron, and fine treated 3 micron products is shown below in Figure 6.18 to help show how the impacts vary for the diverse portfolio of calcium carbonate products. The screened and coarse dry impacts are significantly lower than those for the fine products. This is because of the lower amount of natural gas and electricity used to manufacture these products. In addition, the fine 3 micron products require more processing steps than the others.

Table 6.16 - Overall Environmental Impacts for Each Calcium Carbonate Product (per dry ton of product)

Impact Category	Unit (per dry ton)	Screened Grade	Coarse Dry 30µg	Coarse Dry 20µg	Fine Slurry 3µg	Fine Treated 3µg
Global Warming	kg CO_2 eq	2.24E+01	3.11E+01	5.22E+01	1.83E+02	2.69E+02
Fossil Fuel Depletion	MJ surplus	2.29E+01	3.36E+01	6.12E+01	1.64E+02	2.22E+02
Eutrophication	kg N eq	2.80E-02	2.45E-02	3.81E-02	8.30E-02	1.83E-01
Smog	kg O_3 eq	9.74E+00	8.83E+00	1.54E+01	2.49E+01	2.98E+01
Acidification	kg SO_2 eq	4.72E-01	4.64E-01	7.41E-01	1.90E+00	2.58E+00
Ozone Depletion	kg CFC_{-11} eq	2.66E-07	2.89E-07	3.04E-07	1.05E-06	2.53E-06
Carcinogenics	CTU_h	3.91E-07	3.68E-07	6.07E-07	1.28E-06	2.38E-06
Non-carcinogenics	CTU_h	1.77E-06	2.44E-06	4.33E-06	1.03E-05	1.24E-05
Respiratory Effects	kg $PM_{2.5}$ eq	1.91E-02	1.82E-02	2.67E-02	8.54E-02	1.58E-01
Ecotoxicity	CTU_E	3.64E+01	5.16E+01	8.64E+01	1.85E+02	3.22E+02
Cumulative Energy Demand	MJ	3.12E+02	4.33E+02	7.27E+02	2.66E+03	4.36E+03

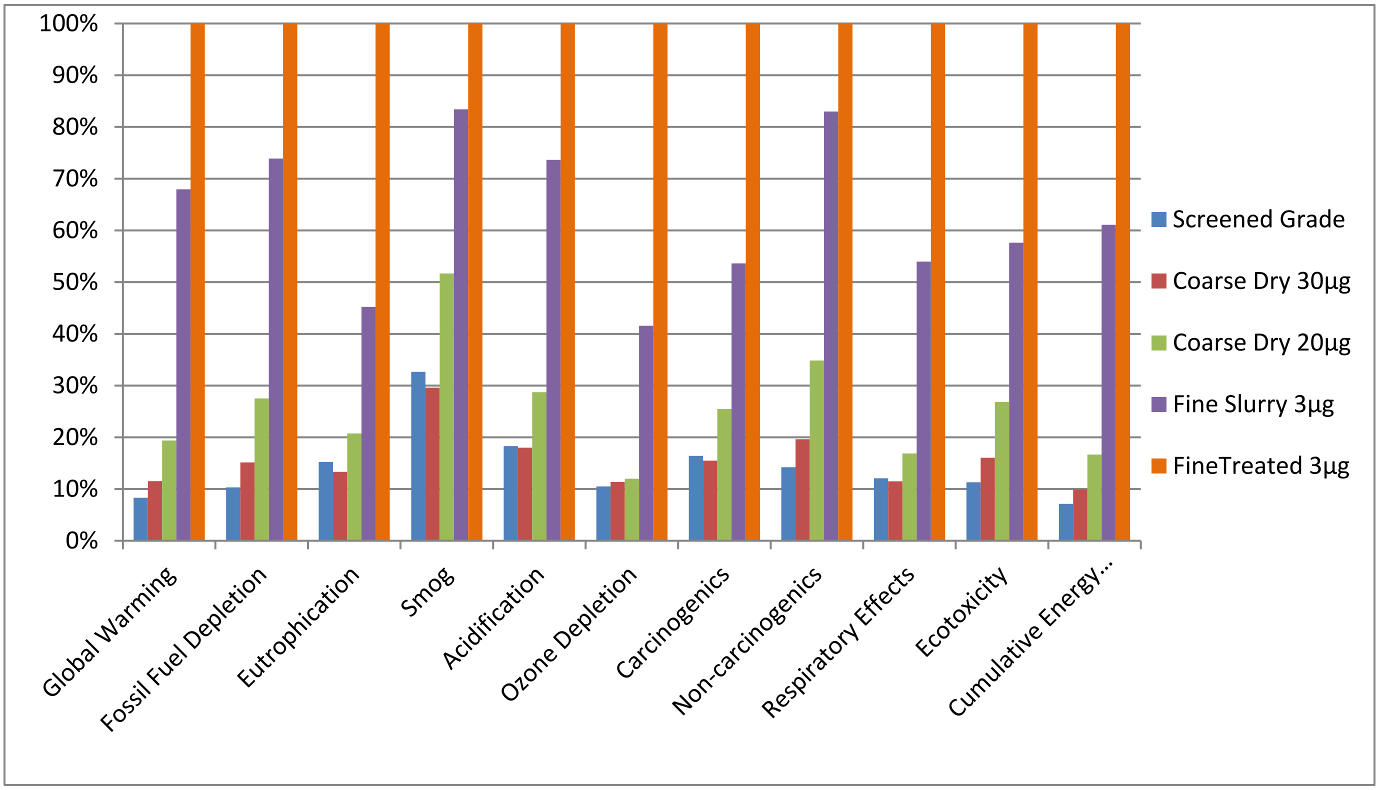

Figure 6.18 - Environmental Impacts of Calcium Carbonate Products (per Dry Ton of Product)

7.0 Additional Analysis

7.1 Distribution Scenarios

In addition to the cradle-to-gate impacts examined in this study, there will also be impacts associated with transporting the finished product to the customer. An analysis was done to compare the Global warming potential of finished product transportation to the cradle-to-gate impacts of each product.

Table 7.1 - Calcium Carbonate Distribution Comparison

	Cradle-to-Gate Carbon Footprint					Transport Distance by Truck			Transport Distance by Rail		
	Screened Grade	Coarse 30µg	Coarse 20µg	Fine Slurry	Fine Treated	500 miles	1,000 miles	2,000 miles	500 miles	1,000 miles	2,000 miles
Global Warming Potential (kg CO_2 eq/ton)	22	31	52	183	269	69	137	275	39	78	156

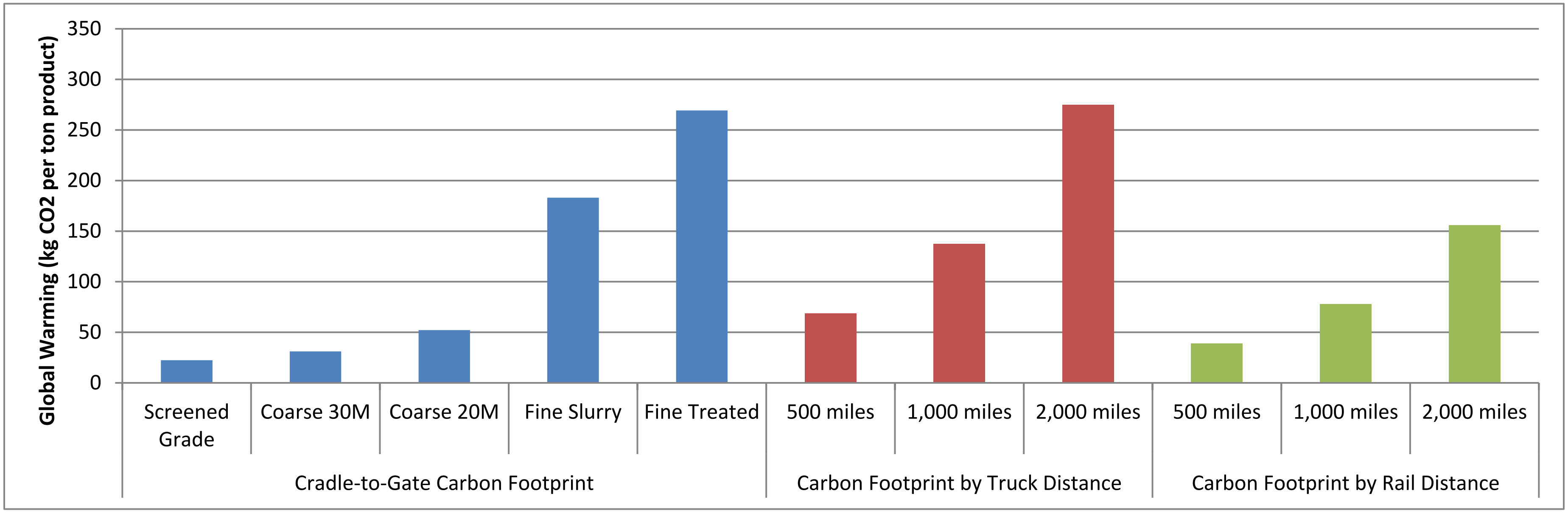

Figure 7.1 - Calcium Carbonate Distribution Comparison

The data shows that truck transport has a higher impact than rail transport. Also, an addition of 2,000 miles of transport by truck will double global warming impacts of the fine treated product.

7.2 European Data Comparison

There was a life-cycle analysis done for IMA-EU for their calcium carbonate. A comparison of the results of that study with this LCA is shown below. IMA-EU used a different impact assessment methodology for their analysis, thus we reanalyzed the IMA-NA data and adjusted accordingly. Please note that life cycle assessment studies vary in scope, system boundaries, data quality, formulation, technology, geography, time period, value choices, and others. This variability inevitably leads to different results, and thus very few LCA studies can be compared exactly.

Table 7.2 - IMA-EU and IMA-NA Coarse Comparison

	Unit	IMA-NA Screened Grade	IMA-NA Coarse Dry 30µg	IMA-NA Coarse Dry 20µg	IMA Europe - Coarse >63µg
Primary Energy Consumption	MJ	2.83E+02	3.93E+02	6.59E+02	6.81E+02
Water Consumption	L	6.58E+01	4.83E+01	8.08E+01	6.19E+00
Abiotic Depletion	Kg Sb eq.	1.23E-05	8.22E-06	1.07E-05	2.22E-07
Global Warming Potential	Kg CO_2 eq.	2.47E+01	3.42E+01	5.75E+01	3.97E+01
Acidification	Kg SO_2 eq.	4.39E-01	4.49E-01	7.10E-01	3.31E-02
Photo-oxidant Formation	Kg C_2H_4 eq.	1.37E-02	1.66E-02	2.54E-02	1.40E-02
Eutrophication	Kg PO_4 eq.	7.68E-02	6.69E-02	1.08E-01	8.88E-03

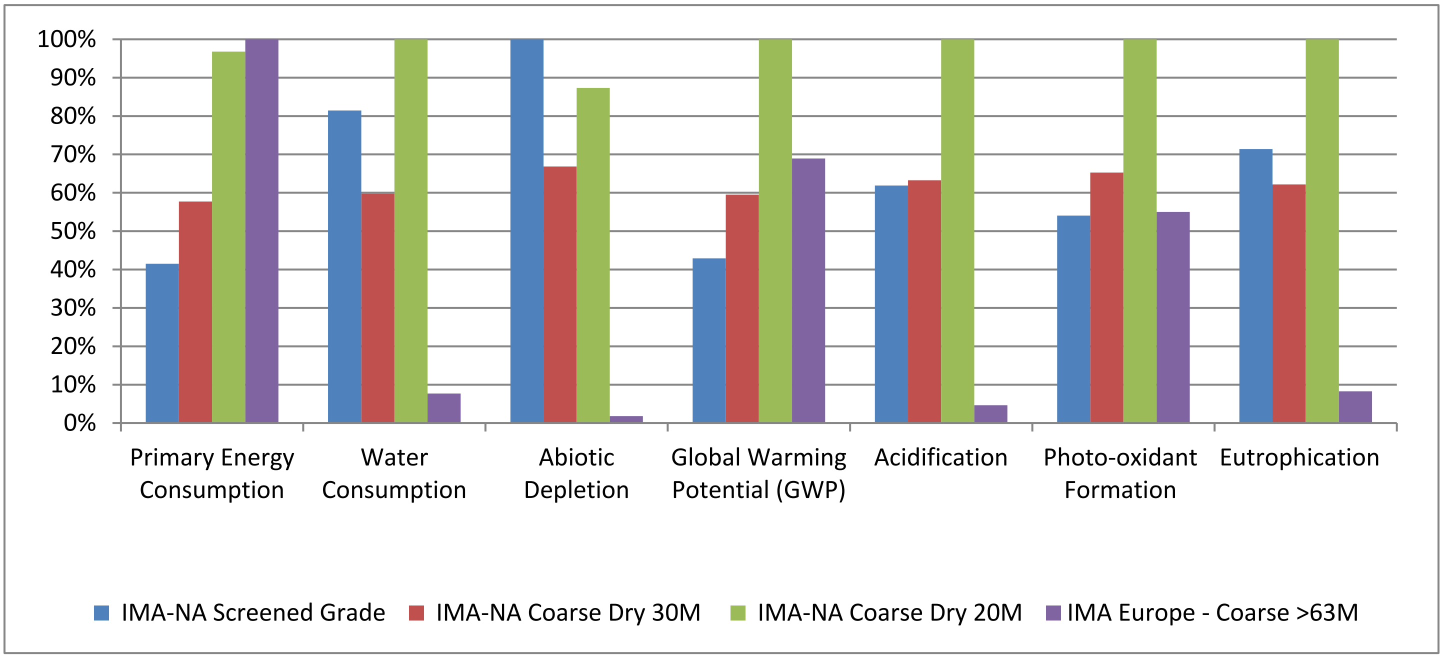

Figure 7.2 - IMA-EU and IMA-NA Coarse Comparison

For most of the impact categories, the North American coarse dry 20-micron product has the largest impact from a cradle-to-gate perspective.

Table 7.3 - IMA-EU and IMA-NA Slurry Comparison

	Unit	IMA-NA Fine Slurry	IMA Europe GCC-Slurry	IMA Europe PCC-Slurry
Primary Energy Consumption	MJ	2.42E+03	2.43E+03	5.19E+03
Water Consumption	L	2.10E+03	6.10E+02	4.67E+03
Abiotic Depletion	Kg Sb eq.	4.71E-05	7.75E-01	2.10E+00
Global Warming Potential	Kg CO_2 eq.	2.02E+02	1.15E+02	3.54E+02
Acidification	Kg SO_2 eq.	2.06E+00	5.73E-01	1.12E+00
Photo-oxidant Formation	Kg C_2H_4 eq.	9.90E-02	4.80E-02	1.78E-01
Eutrophication	Kg PO_4 eq.	1.76E-01	1.06E-01	1.62E-01

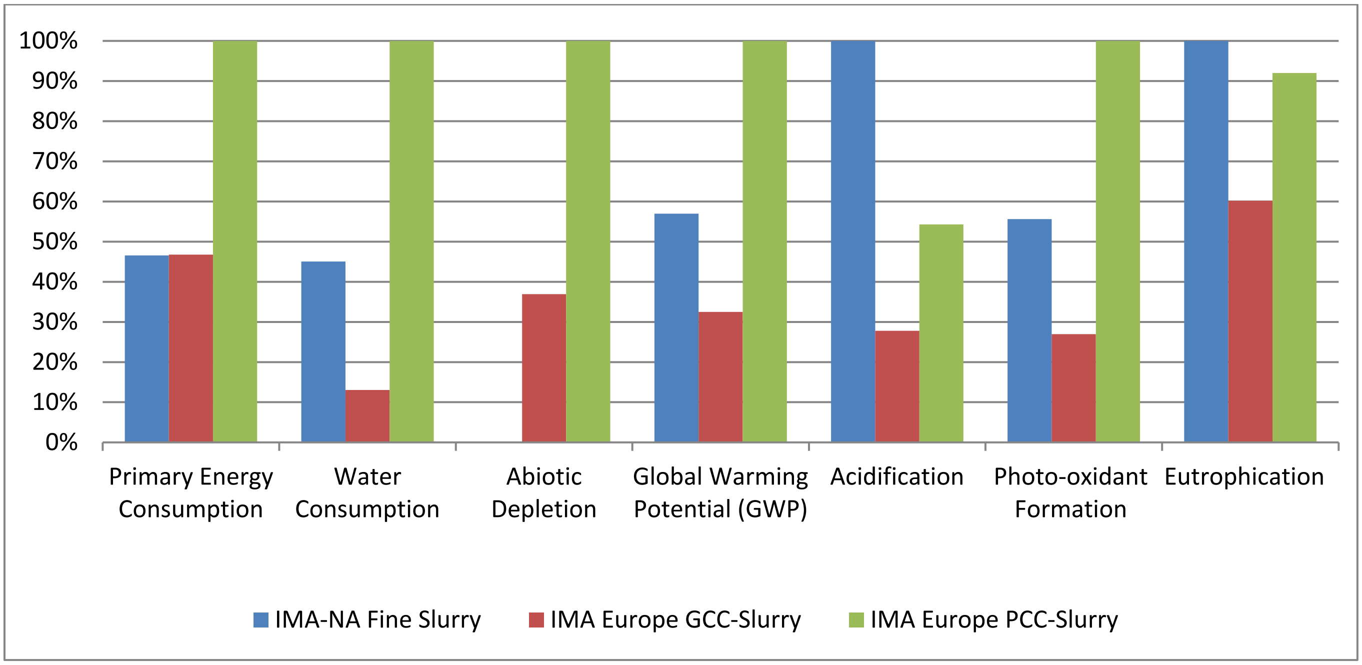

Figure 7.3 - IMA-EU and IMA-NA Slurry Comparison

As shown in the table and figure above, the European PCC slurry has the largest impact in most of the categories. The NA fine slurry impacts are the highest within the acidification and eutrophication impact categories. Note that the European GCC and PCC product is not a product analyzed in the IMA-NA study

Table 7.4 - IMA-EU and IMA-NA Treated Comparison

	Unit	NA Fine Treated ~1% stearic acid	EU GCC-Coated: 1% stearic acid	EU GCC-Coated: 3% stearic acid	EU GCC-Coated: 5% stearic acid
Primary Energy Consumption	MJ	4.0E+03	4.9E+03	7.6E+03	9.3E+03
Abiotic Depletion	Kg Sb eq.	1.2E-04	3.6E-01	3.6E-01	3.6E-01
Global Warming Potential	Kg CO_2 eq.	3.0E+02	3.1E+02	5.5E+02	7.8E+02
Acidification	Kg SO_2 eq.	2.9E+00	2.0E+00	3.4E+00	4.7E+00
Photo-oxidant Formation	Kg C_2H_4 eq.	1.8E-01	2.8E-01	6.9E-01	1.2E+00
Eutrophication	Kg PO_4 eq.	2.6E-01	1.0E-01	1.5E-01	1.9E-01

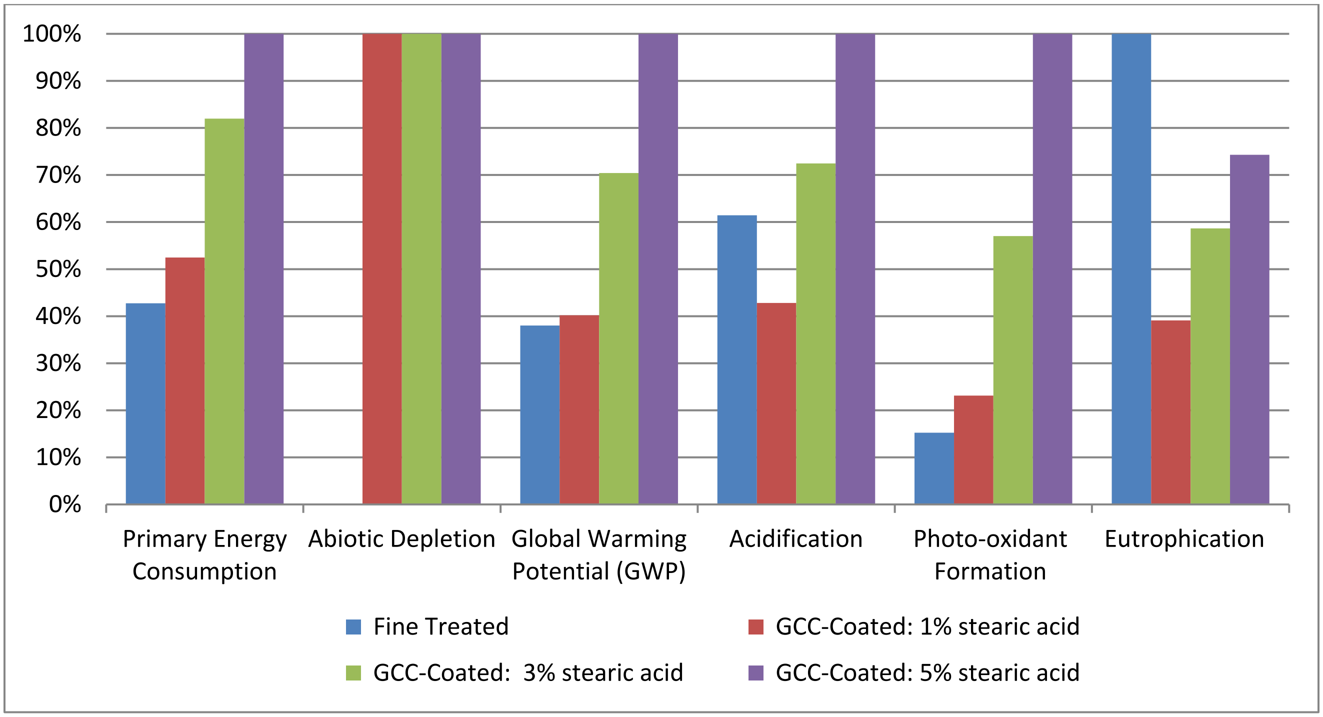

Figure 7.4 - IMA-EU and IMA-NA Treated Comparison

These results show that the EU GCC Coated 5% stearic acid product has a larger impact than the others do in all categories but eutrophication, where the NA fine treated product has the largest impact.

8.0 Limitations

This LCA is for internal use only and has not undergone formal peer review, as is required by ISO 14040 Standards, for external release. The study was conducted following appropriate ISO standards and best practices, but is intended for internal use to assist IMA-NA with understanding the life cycle impacts of their products.

All data for the operation of the quarries and plants, as well as transportation distances and modes, was collected directly from the participating members of IMA-NA. Efforts were made to check the data for internal consistency and to verify data with plant personnel.

The findings in this research are limited by the inherent uncertainty of creating a representative model through LCA. Many assumptions were made in modeling the product system with representative processes and datasets. The authors addressed the uncertainty in modeling decisions by conducting a mass balance and sensitivity analysis as the LCI model was being constructed (data verification/validation relative to cut-off criteria and study goals).

There exists limitation within the secondary data used for the material processes. These limitations may include lack of exact composition for various support materials resulting in the use of proxies and the use of average technologies for upstream production of support materials.

While quality control was undertaken at each step in building the LCI and conducting the LCIA, uncertainty is still present in the results since the data evaluated represents only one year of manufacturing information. Detailed evaluation of multiple manufacturing plants and times would reduce the uncertainty. Some level of uncertainty is inherent in conducting LCA and decision-making must reflect this fact.

Some companies use different variations of the same materials. Thus, an effort was made to combine similar materials to reflect adequately the inputs and outputs used in each plant location. The models for certain materials were based on the most popular variation used.

9.0 Conclusions

Based on the results from the life cycle assessment, the life cycle impacts are strongly driven by the quarry and plant processing. The plant support materials with the highest impact vary depending on the product between stearic acid, dispersant, and the steel screen. For the quarry, the highest impact material is the explosive. Increasing energy efficiency, decreasing process losses, and implementing supplier sustainability requirements can reduce impacts in the processing phase. Finding more methods to recycle or reuse waste materials can also reduce waste disposal impacts.

IMA-NA calcium carbonate producers have direct control over the modes of transportation for support materials, as well as the manufacturing process. Any opportunities to reduce energy consumption in these areas will directly reduce the environmental impacts. It will also provide cost savings and potential competitive advantage. Finding, vetting and selecting more local support material suppliers, such as stearic acid, from sustainably managed sources will further improve environmental performance.

10.0 Recommendations

This information can prepare IMA-NA calcium carbonate companies for future sustainable supply chain requirements and can form the basis of marketing literature focused on environmental benefits. This LCA will also assist these companies with modeling and evaluating any green product claims by competitors.

Calcium Carbonate producers should use this life cycle assessment for evaluating alternate support materials and source locations, and alternate transportation modes as part of a sustainable product development process. IMA-NA should use the information from developing this LCA to take a leadership position in sustainable product development, as well as use this as a basis to meet future requirements for customer sustainable purchasing programs and government requirements. IMA-NA companies should also use the LCA to take a leadership position for any future industry activities related to LCAs, PCRs, or EPDs in order to maintain a competitive position.

Calcium Carbonate producers should evaluate opportunities for energy conservation including waste heat recovery and process optimization to reduce energy consumption and related impacts in the plant processing operations. Sub-metering of energy use for each critical stage in the manufacturing process would allow for a more detailed analysis and is recommended

Sustainable Solutions Corporation is recommending publication of the calcium carbonate data after the study has gone through a critical review. This industry-averaged LCA should be reviewed and submitted to USLCI for this data to be used by LCA practitioners. This LCA can be used by IMA-NA companies as a basis for publication of the Calcium Carbonate LCA data if market conditions, government requirements or customers should require public release of the data in the future.

Appendix A: Process Flow Diagrams

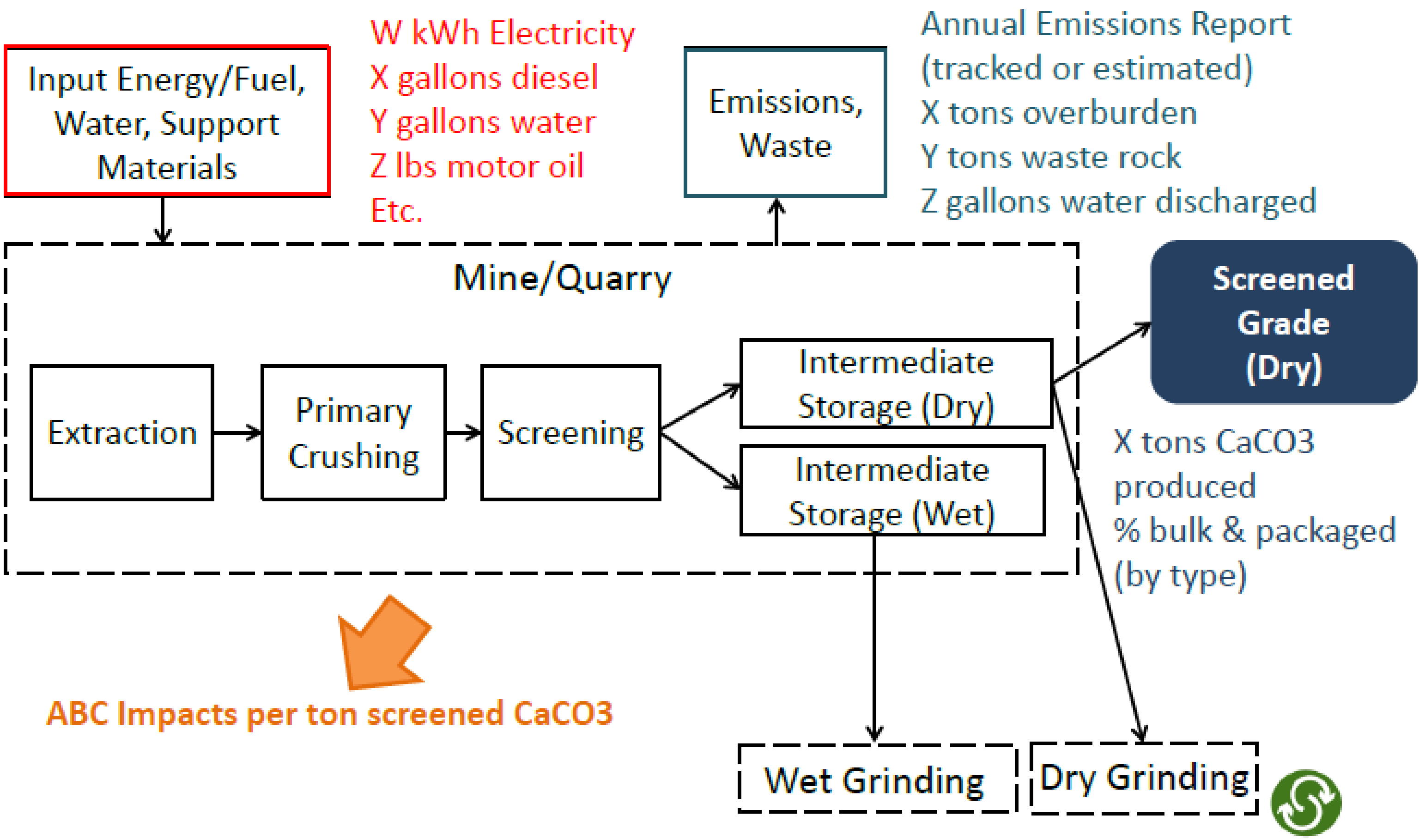

Figure A.1 - Mining/Quarrying Process Flow Diagram for CaCO3

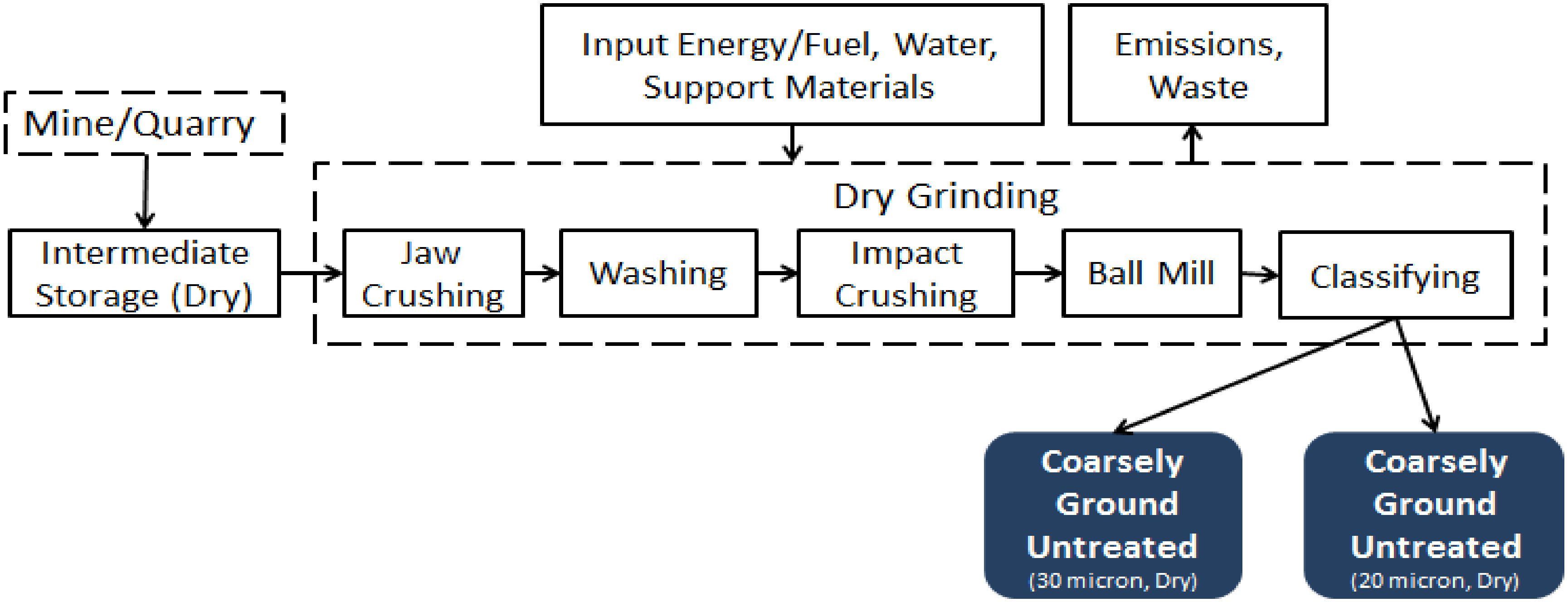

Figure A.2 - Dry Grinding Process Flow Diagram for CaCO3

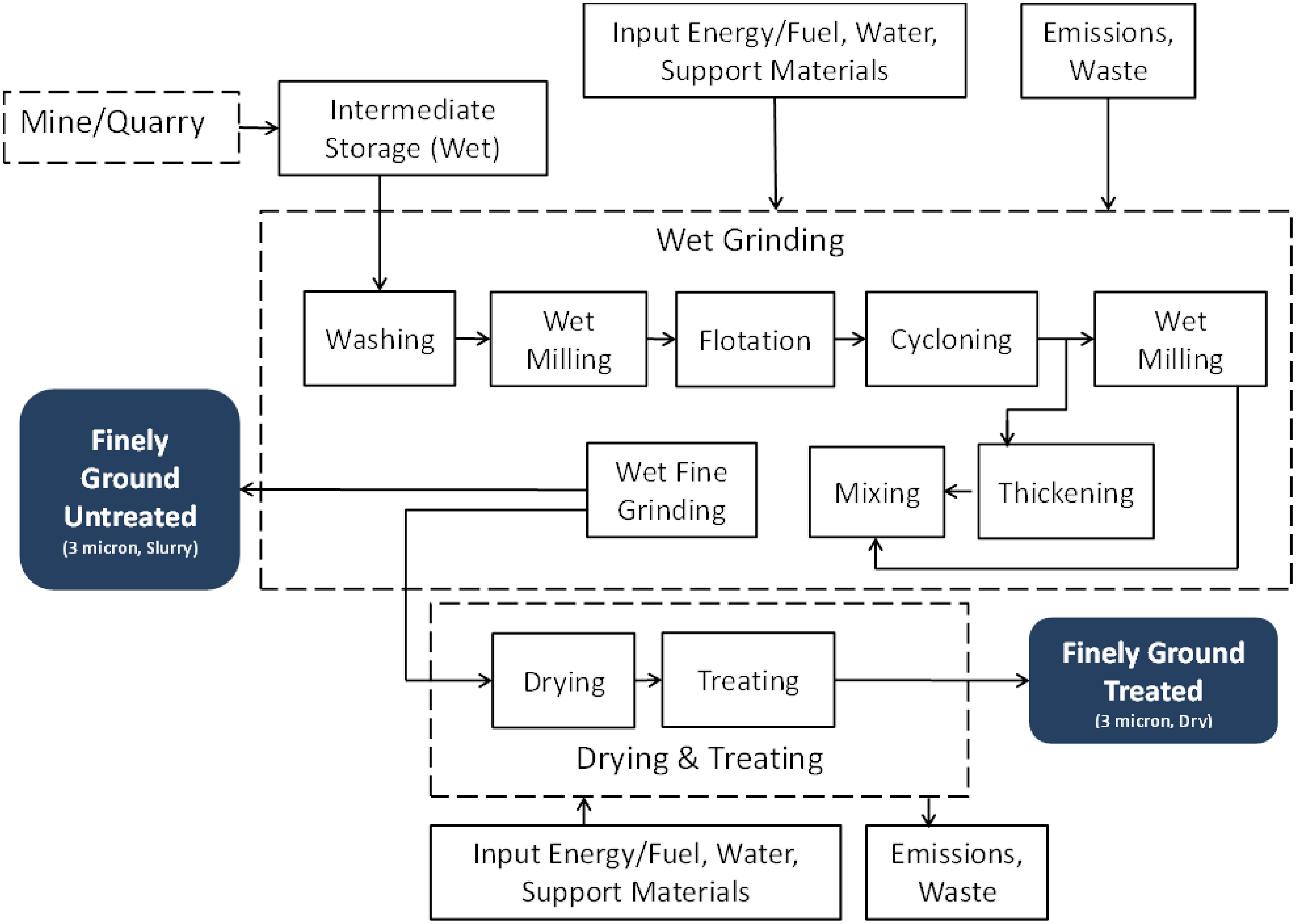

Figure A.3 - Wet Grinding and Drying and Treating Process Flow Diagram for $CaCO_3$

Appendix B: Sensitivity Analysis

B.1 Electricity Sources

The electricity used by all companies is based on an average grid for the US. Because of the high impact of electricity in the plant processing operations, an analysis was done for the best and worst-case electricity scenarios with the worst being the eastern US grid mix and the best being the western US grid mix. The plants involved in this analysis are scattered in North America in areas with very different grid mixes.

Table B.1 - Coarse Dry 30µg and Fine Treated 3µg Electricity GWP (kg CO2 eq/dry ton)

Product	Electricity-Eastern US	Electricity-Base	Electricity-Western US
Coarse Dry 30µg	1.96E+01	1.65E+01	1.36E+01
Fine Treated 3µg	2.48E+02	2.08E+02	1.73E+02

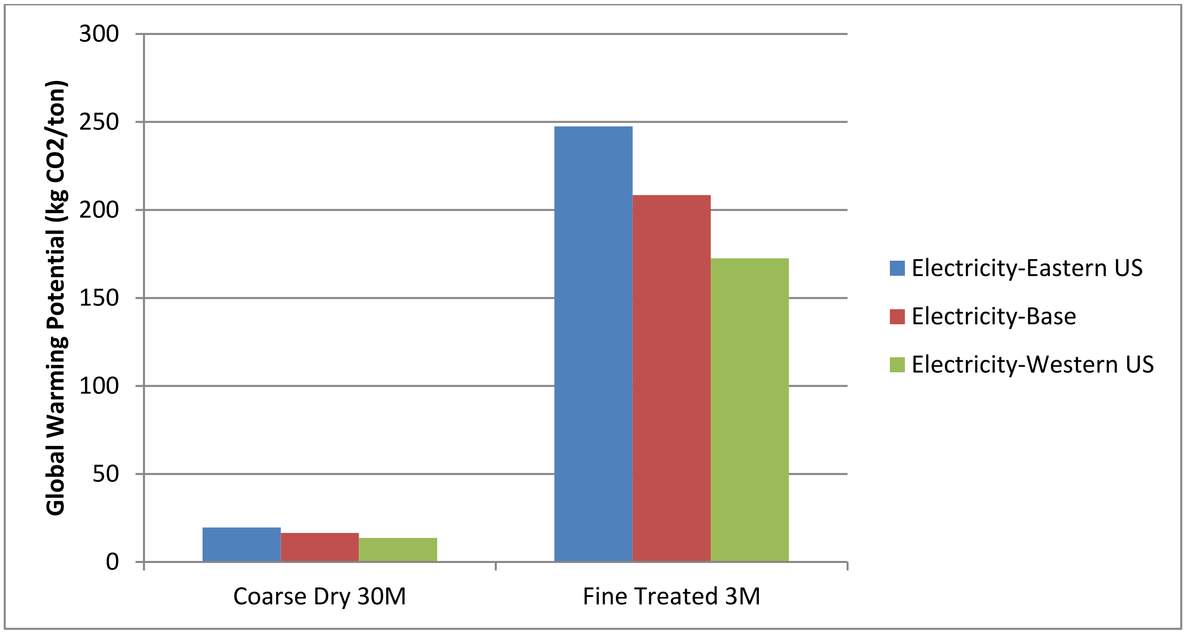

Figure B.1 - Coarse Dry 30µg and Fine Treated 3µg Electricity GWP (kg CO2 eq/dry ton) Comparison

As shown by the table and figure above, a difference of grid mixes influence the global warming potential of the finer products more than the others do.

The data below is a comparison of the impacts of one kWh of produced electricity from each electricity grid analyzed above.

Table B.2 - US Electricity Grid TRACI Comparisons

Impact Category	Unit	Electricity-Eastern US	Electricity-Base	Electricity-Western US
Global Warming	kg CO_2 eq	8.16E-01	6.87E-01	5.68E-01
Fossil Fuel Depletion	MJ surplus	3.66E-01	4.65E-01	5.00E-01
Eutrophication	kg N eq	1.02E-04	8.13E-05	6.50E-05
Smog	kg O_3 eq	5.75E-02	4.21E-02	3.44E-02
Acidification	kg SO_2 eq	7.00E-03	5.98E-03	4.89E-03
Ozone Depletion	kg CFC$_{-11}$ eq	1.58E-11	1.13E-11	8.00E-12
Carcinogenics	CTU$_h$	1.38E-09	1.16E-09	1.15E-09
Non-carcinogenics	CTU$_h$	2.46E-08	2.12E-08	1.90E-08
Respiratory Effects	kg PM$_{2.5}$ eq	3.37E-04	2.98E-04	2.53E-04
Ecotoxicity	CTU$_E$	2.62E-01	2.76E-01	2.93E-01
Cumulative Energy Demand	MJ	1.11E+01	9.77E+00	8.24E+00

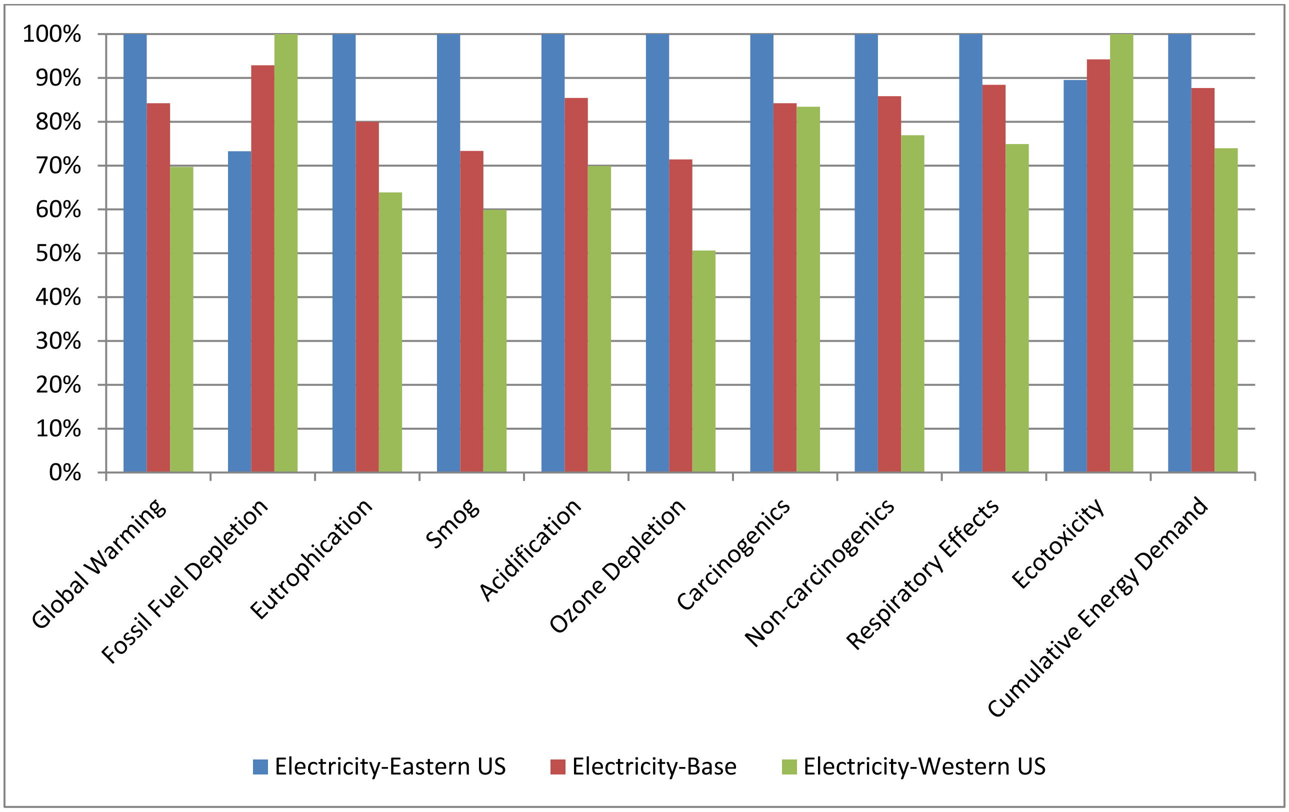

Figure B.2 - US Electricity Grid TRACI Comparisons

For all of the impact categories, the western US grid has the lowest impact. The biggest difference between the electricity grids can be seen in the ozone depletion category. The western grid is less impactful because it uses a smaller amount of fossil fuels and more renewable sources.

B.2 Transportation Methods

The plant support material transportation impacts are significant in the life cycle of most of the products, especially for the fine products. An analysis was done to compare the GWP of the transportation of the calcium carbonate products' support material transport with a set distance of one mile for each transportation mode.

Table B.3 - Plant Support Material Transportation GWP (kg CO_2 eq) Impact Comparison per ton of product

Transportation GWP (kg CO2 eq per ton)	Base	1 Mile
Screened Grade	1.93E-01	1.86E-01
Coarse Dry 30µg	5.48E+00	2.53E-01
Coarse Dry 20µg	1.70E+01	2.61E-01
Fine Slurry 3µg	1.56E+01	3.07E-01
Fine Treated 3µg	1.54E+01	3.14E-01

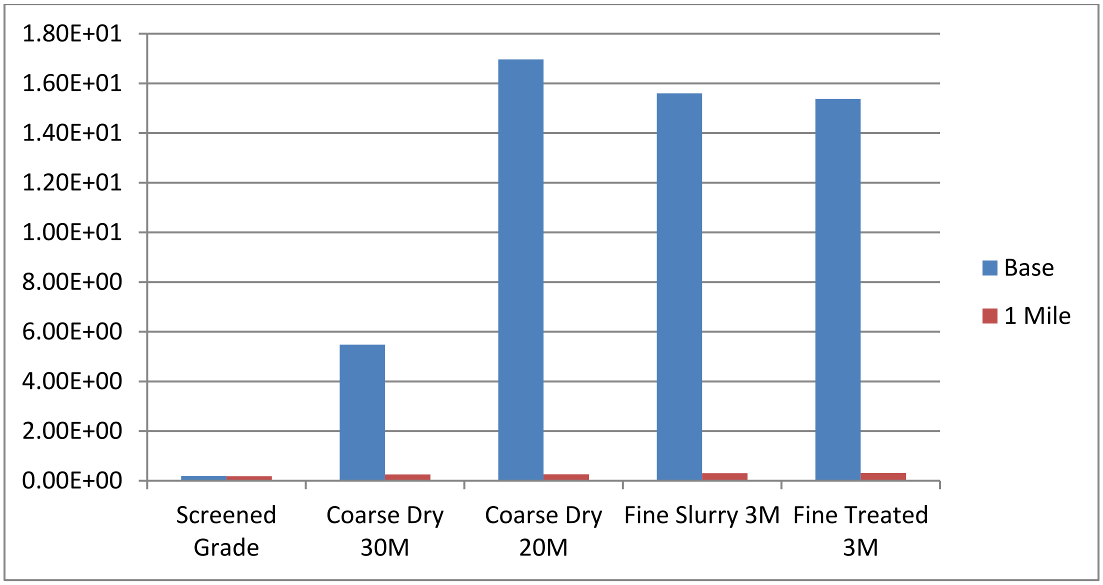

Figure B.3 - Plant Support Material Transportation GWP (kg CO2 eq) Impact Comparison per Ton of Product

For the one-mile scenario, the only thing that varies between the different products is the weight of the materials being transported and the modes of transport used. The products with the highest transportation impacts have barge transport as a mode of transportation.

Appendix C: US LCI Submission SI Conversion

The intent of this industry-wide study is to make this study available through the US Life Cycle Inventory database. In order to publish, the US LCI database requires units to be reported using the International System of Units (SI Units). The following tables parallel the tables found in Section 4, but are converted to SI units.

C.1 Support Materials Overview

Table C. 1 - Calcium Carbonate Quarry Support Materials

Support Materials (Quarry)	Unit	Quarry Amount
Oil & Grease (equipment maintenance)	liters	5.60E-02
Antifreeze	liters	7.84E-03
Explosives	kg	5.62E-01
Battery	kg	9.53E-04
Filters (air, oil, fuel)	kg	8.94E-03
Tires	kg	9.30E-03
Winterizing Agent	liters	2.90E-02

Table C. 2 - Calcium Carbonate Plant Support Materials

Support Materials (Plants)	Unit	Screened	Coarse 30µg	Coarse 20µg	Fine Slurry 3µg	Fine Treated 3µg
Input Stone from Quarry	metric tonnes	1.23E+00	9.43E-01	1.09E+00	1.28E+00	1.31E+00
Shaker Screen (Steel)	kg	1.24E-02	2.01E-03	1.08E-02	2.88E-05	6.30E-05
Conveyor Belt	meters	5.97E-04	4.66E-04	3.63E-04	2.41E-04	3.20E-04
Biocides	kg	-	-	-	2.89E-02	2.37E-02
Urethane Screen	kg	-	-	-	1.66E-03	1.36E-03
Flotation Agent	kg	-	-	-	9.07E-01	5.72E-01
Dispersant	kg	-	-	-	3.83E+00	3.13E+00
Grinding Media 2	kg	-	-	-	1.34E-01	1.09E-01
Stearic Acid	kg	-	-	-	-	1.10E+01
Grinding Media 1	kg	-	-	-	1.50E-01	2.49E-01
Suspension Aid	kg	-	-	-	7.21E-03	1.58E-02
Plastic Bag Filters	kg	-	-	-	5.31E-04	1.50E-02
Heat Transfer Fluid	kg	-	-	-	-	5.31E-03
Lube Gear Oil Grease	kg	-	-	-	-	3.95E-04
Sock Filters	kg	-	-	-	5.94E-04	4.85E-04

C.2 Extraction and Processing Overview

Table C. 3 - Quarry Materials and Fuels Inventory (per ton of product)

Energy Inputs (Quarry)	Unit	Quantity
Electricity	MJ	1.15E+01
Gasoline	L	1.21E-02
Diesel	L	1.40E+00
Waste Fuel Oil	gal	2.44E-01
Waste	**Unit**	**Quantity**
Waste stone/overburden to Earth	metric tonnes	9.53E-01
Waste stone/overburden to Recycle	metric tonnes	2.20E-02
Waste solids to Landfill	kg	1.76E-02
Waste solids to Recycle	kg	1.51E-03
Waste liquids to Recycle	L	6.40E-02
Air Emissions	**Unit**	**Quantity**
Particulates to Air	kg	1.90E-02
Transportation	**Unit**	**Quantity**
Truck	kg-km	5.11E-02

Table C. 4 - Plant Manufacturing Process Materials and Fuels Inventory (per ton of product)

Energy Inputs (Plants)	Unit	Screened	Coarse Dry 30μg	Coarse Dry 20μg	Fine Slurry 3μg	Fine Treated 3μg
Electricity	MJ	5.80E+01	8.64E+01	1.33E+02	7.74E+02	1.09E+03
Natural Gas	L	4.73E+00	3.74E-01	2.32E-01	2.19E-02	2.76E+01
Propane	L	-	3.05E-01	-	-	-
Water	**Unit**	**Screened**	**Coarse Dry 30μg**	**Coarse Dry 20μg**	**Fine Slurry 3μg**	**Fine Treated 3μg**
Water Inflow	L	-	0.17	-	51.48	103.72
Water Outflow*	L	-	0.17	-	51.48	103.72
Waste	**Unit**	**Screened**	**Coarse Dry 30μg**	**Coarse Dry 20μg**	**Fine Slurry 3μg**	**Fine Treated 3μg**
Waste sand/mud to Earth	metric tonnes	1.50E-01	2.75E-02	2.23E-01	5.57E-02	1.22E-01
Waste to Landfill	kg	1.23E-02	-	-	9.75E+00	2.13E+01
Waste to Recycle	kg	9.39E-04	2.70E-03	1.14E-02	3.78E-03	3.65E-03
Air Emissions	**Unit**	**Screened**	**Coarse Dry 30μg**	**Coarse Dry 20μg**	**Fine Slurry 3μg**	**Fine Treated 3μg**
Particulates to Air	kg	2.85E-02	4.43E-04	1.31E+00	1.60E-02	1.49E-02
Transportation	**Unit**	**Screened**	**Coarse Dry 30μg**	**Coarse Dry 20μg**	**Fine Slurry 3μg**	**Fine Treated 3μg**
Truck	kg-km	2.01E+00	5.83E+01	4.74E+01	1.27E+01	2.25E+01
Rail	kg-km	-	-	2.29E+02	2.57E+02	2.13E+02
Barge	kg-km	-	-	2.41E+02	2.70E+02	2.63E+02

*Water outflow is not tracked by plant operators. No process water is sent for municipal wastewater treatment but is evaporated or stored in retention ponds for reuse.

Industrial Ecology Consultants
35 Bracebridge Road
Newton, Massachusetts 02459

Appendix D: Critical Review by Independent Third Party

The Industrial Minerals Association North America (IMA-NA) commissioned the Sustainable Solutions Corporation to conduct a Life Cycle Assessment (LCA) study. The objective of this study was to develop an industry average LCA for North American-mined/quarried calcium carbonate to provide the members with a detailed understanding of the environmental impacts throughout the cradle-to-gate extraction and production processes. The results of the study are to then be used to examine opportunities for process and material improvements as well as provide potential public information. As such, Industrial Ecology Consultants reviewed the LCA study regarding conformance to the ISO 14040 and 14044 standards on LCA.

Critical Review Objectives and Procedures

Per the International Organization of Standardization (ISO) 14044 standard, the critical review process includes the following objectives to ensure conformance to the applicable standards to conduct a Life Cycle Assessment (LCA) study:

- The methods used to carry out the LCA were consistent with the applicable international standards and methodologies,
- The methods used to carry out the LCA were scientifically and technically valid,
- The data used were appropriate and reasonable in relation to the goal of the study,
- The interpretations reflected the limitations identified and the goal of the study, and
- The study report was transparent and consistent.

The Sustainable Solutions Corporation provided a comprehensive report that was evaluated by Industrial Ecology Consultants by completing a review matrix containing the general requirements listed above and the detailed requirements contained within the applicable standards. Sustainable Solutions provided satisfactory responses and/or changes to all comments made.

Review Results

On the basis of the objectives set forth to review this study, Industrial Ecology Consultants concludes that the study conforms to the applicable ISO standards, ISO 14040 and 14044.

Respectfully,

Thomas P. Gloria, Ph.D.

15 November 2016

Newton, Massachusetts, US