

# **COMPARATIVE LIFE CYCLE ASSESSMENT OF CONCRETE AND STEEL AS CONSTRUCTION MATERIAL**

*A thesis submitted in partial fulfilment of the requirements for the award of  
degree of*

**MASTER OF ENGINEERING  
IN  
STRUCTURAL ENGINEERING**



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## DECLARATION

This is to certify that the work which is being presented in the thesis entitled, "Comparative Life Cycle Assessment of Concrete and Steel as Construction Material" in partial fulfilment of the requirements for the award of degree of Master of Engineering in Structural Engineering in Civil Engineering department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Dr. Rafat Siddique and refers other researcher's works which are duly listed in the reference section. The embodied in this thesis has not been submitted anywhere for award of any other degree.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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Concrete and Steel is one of the most widely used construction materials. The demand for concrete and steel as a construction material is ever-growing. The construction industry accounts for almost 75% of total raw material used. This is an obvious drain on natural resources and has a major impact on the surrounding environment. Construction materials are also responsible for a relatively large portion of the global CO<sub>2</sub> emissions. The commercial construction industry is dominated by the use of steel and in-situ concrete as building materials. It is intuitive then, to state that these two materials and their respective production flows have a significant impact on the environment, simply because of the amount of material being produced and consumed in the building industry today. In addition, due to drastic increases in energy prices and potential shortages in the future, the amount of energy consumed in the production of construction materials (embodied energy) and the amount of energy used over a projected life span (operational energy) are becoming increasingly more important to builders, designers, and owners of buildings.

The growing trend in the India, and elsewhere in the world, is towards eco-friendly design. In the last several years, the concrete and steel industries have spent significant resources to promote their material as the optimum solution for sustainable building design. Because natural resource consumption, air emissions, and the amount of embodied energy are all important drivers for the push towards sustainability, this study will compare those factors and quantify the differences between what is necessary for the construction of concrete- and steel-frame structures.

The purpose of this thesis is to utilize the Life Cycle Assessment (LCA) method to compare the environmental impacts created by the steel and concrete construction industry at the lowest common performance level, in this case the structural shell of a typical building in a given geographical area. The study will include all major product systems and material flows involved with concrete or steel construction and quantify their impacts in terms of total energy requirement, natural resources consumed, and harmful air emissions, specifically as they relate to global warming potential.

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# Chapter 1

## Introduction and Organization

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### 1.1 Overview

The commercial construction industry in the world is dominated by the use of steel and reinforced cast-in-place concrete as building materials. Their respective applications in the built environment are well noted since the beginning of the 20<sup>th</sup> century. They have very different characteristics in terms of strength, stiffness, density, and constructability. A brief comparison of steel and concrete, in terms of their positive and negative attributes, is described in Table 1.1.

Table 1.1. Concrete and Steel Characteristics for Construction.

Source: (Madsen, 2005)

	Characteristics
Steel -	+ High strength to weight ratio + Tensile and compressive strength + Ductility + Accurate connection settings
	- Fire-proofing required - Expensive rigid connections (weld)
Concrete -	+ Formable; molded to any required shape + Durable + Fire resistant + Rigid connections
	- Compressive strength only - Labor-intensive

The concrete and steel industries have competed for construction market share throughout their history. Differences in labor skill level and wages, material availability and cost, and structural performance characteristics are the normal decision-making factors used by architects and engineers to choose the most suitable building material for their specific location and building type (Barry et al., 2001).

Coincidentally, the rise of sustainable construction practices has led to severe competition among the two major commercial building materials, steel and concrete, each claiming to be the 'best' choice and touting their performance in terms of sustainability. But which material is better? Can a single research study answer that? The simple answer is no; the scope of the first question is far too broad and comprehensive to obtain a definitive answer. The answer really depends on the intended purpose and scope of the comparison. If those elements are clearly defined, a legitimate comparison can be achieved.

## **1.2 Life Cycle Assessment Method**

Industrial ecology is certainly not a new field of study, but it is emerging now, along with environmental management and sustainable design, as an important research area for developing solutions to today's environmental challenges. Several analysis methods are utilized in conjunction with the study of industrial ecology and environmental management; one of these methods is Life Cycle Assessment (LCA). The LCA methodology was established in the 1990s by the Society of Environmental Toxicology and Chemistry (SETAC) and later formalized by the International Standards Organization (ISO) as a means to assess environmental impacts of a product system. The LCA method is used because it is well suited for the intended purpose of this research study; a comparison of two materials.

## **1.3 Environmental Impacts Defined**

The environmental concerns that serve as the focus for this study are:

- Acidification Potential
- Aquatic Eutrophication Potential
- Global Warming Potential
- Ozone Depletion Potential
- Smog Potential
- Total Primary Energy
- Non Renewable Energy
- Fossil Fuel Consumption

The basis for choosing these three environmental factors is discussed in greater detail in the following sections.

### 1.3.1 Energy Consumption

This research study focuses on consumption of energy because of its relevance in today's world. Increased energy prices and instability in the major oil producing countries have placed energy at the top of national political discussions and industrial sector challenges. The potential for energy shortages in the not so distant future has spurred debate on the necessity of alternative energy sources and the need to improve energy efficiencies in existing systems (Kibert et al., 2005).

Building energy consumption can be subdivided into two categories;

1) Embodied energy defined as the energy used in its construction and pre-use phase; and 2) operational energy defined as the amount of energy required to operate and maintain the structure, including; providing heat, air-conditioning, lights, water, etc, for the building occupants (Kibert et al., 2005). The relationship between embodied and operational energy is highlighted in Figure 1.1.

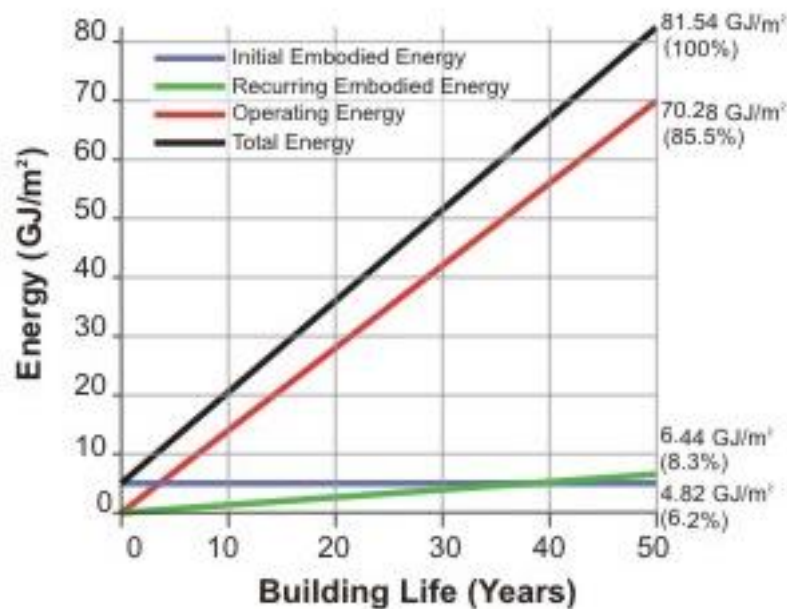


Figure 1.1. Embodied vs. Operational Energy

Source: (Cole and Kernan et al, 1996)

### **1.3.2 Air Emissions**

Harmful air emissions have become a major issue in today's world due to the effects of global warming and discernable climate changes over the past decade. The facts are that the building industry is the largest contributor to the total upstream CO<sub>2</sub> emissions accounting for 7% of the annual global greenhouse gas emissions (McMath and Fisk et al., 1999). CO<sub>2</sub> and other hazardous emissions from steel and concrete are examined because of their obviously harmful effects.

### **1.3.3 Resource Depletion**

The construction industry accounts for a vast majority of the raw materials consumed in the world. This enormous consumption rate, poses a major environmental challenge because of the limited supply of natural resources on hand. The extraction and use of natural resources has significant potential impact on the environment (Graedel and Allenby et al., 2003).

Newer concretes with recycled admixtures and the refinement of the steel manufacturing process to nearly 100% recycled content are just some examples of the industries' solutions to the environmental challenges related to their materials. This thesis, using the LCA method, compares the environmental impacts associated with the two materials.

## **1.4 Research Objectives**

This research study applies the LCA methodology in order to compare concrete and steel when they are used as building materials. The major goals of this research study are to:

- 1) Provide a detailed life cycle analysis of steel and concrete on a tangible and performance-level basis in terms of energy consumption, harmful air emissions, and natural resource depletion.
- 2) Serve as a tool to compare construction materials in terms of sustainability on the individual building level and identify areas for potential improvement.

## **1.5 Goal Definition and Scope**

### **1.5.1 Goal Definition**

The first step in conducting an LCA is to clearly define the goals of the analysis. It is critically important to state the intended purpose and application of the study (Graedel and Allenby et al., 2003; Kotaji et al., 2003). The essential elements of goal definition are outlined in the following sections.

### **1.5.2 Purpose**

The purpose of this thesis is to compare the environmental impacts associated with steel and cast-in-place concrete, as they relate to the building construction industry. This will be discussed further as the functional unit of the LCA is defined in later sections.

This study uses the construction to quantify the environmental impact of these major building materials.

### **1.5.3 Scope**

In order to produce tangible results as they relate to sustainable construction, this LCA is intentionally narrow in breadth. It attempts to compare steel and concrete at the lowest possible common performance level in terms of the construction industry, as defined by the functional unit description in the next section. The scope concentrates solely on the buildings and therefore this LCA is further defined as a cradle-to-grave analysis of the respective building materials using Athena Impact Estimator for Buildings. Design of functional units is out of scope of this study. Details of system boundaries are mentioned in Appendix-A.

### **1.5.4 Functional Unit**

The purpose of the functional unit in the LCA methodology is to provide "a reference to which the inputs and outputs are related." (ISO 14040, 2006). It is a critical piece of information for executing a proper assessment and ensuring a legitimate and accurate comparison of materials. The functional unit must correspond to results being achieved. In the case of this study, simply comparing a given volume of concrete and steel is flawed, because the materials have different performance characteristics and structural properties. For instance a cubic meter of

concrete has very different performance characteristic than a cubic meter of steel. The backbone of this research study, and any LCA for that matter, is defining a functional unit that serves to equate the respective materials on a comparable performance basis (ISO 14040, 2006). The functional units for this LCA is mentioned in detail in Chapter 6.

## **1.6 Organization of Thesis**

The report is organised into seven chapters. The organisation of chapters is as follows:

Chapter 1: Introduction and Organization; introduces the topic, objective of the report, scope and limitation and organization of the thesis.

Chapter 2: Life Cycle Assessment; discussion about LCA, its advantages, application & limitation, concept of LCA & sustainability.

Chapter 3: Review of Existing Literature; a total of seven research work related to LCA in structural building is studied & discussed.

Chapter 4: Construction Process Description; briefly discussed steps for concrete frame structure and steel frame structure.

Chapter 5: Definition of System Boundary

Chapter 6: Interpretation of Results; results are shown & discussed for both concrete building & steel building.

Chapter 7: Conclusion; conclusion is drawn with future scope of study.

## **2.1 Introduction**

Life Cycle Assessment (LCA) is one of several tools used in environmental management. It is used to assess potential environmental impacts through the life cycle of the system under study. This means that the possible impacts associated with every stage of its life cycle are accounted for. LCA consists of four stages: goal definition, inventory analysis, impact assessment and interpretation. With its holistic concept, LCA is found to be useful in several applications. Despite its many advantages, LCA also has limitations as well. These limitations need to be taken into account when making conclusions for an LCA study.

## **2.2 Description of LCA**

### **2.2.1 Definition of LCA**

Life cycle assessment (LCA) is widely known as one of the tools in the area of environmental management (e.g. risk assessment, environmental performance evaluation, environmental auditing and environmental impact assessment). McDougall et al. (2001) illustrated LCA as an environmental management tool used to see how a product or service produced from ‘cradle to grave’. This means that every stages of its life cycle will be examined, from raw materials acquisition, through manufacture, distribution, use, possible recycle/reuse until its final disposal.

Examples of LCA definitions given by different authors are shown below:

Guinee (2002, in the handbook of LCA) defined LCA as “*a tool for the analysis of the environmental burden of products at all stages in their life cycle – from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product to the management after it is discarded, either by reuse, recycling or final disposal (in effect, therefore, ‘from the cradle to the grave’).*”.

The Society for Environmental Toxicology and Chemistry (SETAC) (in the first paragraph) stated that “*LCA addresses the environmental aspects and potential environmental impacts (e.g. resource use and environmental consequences of releases) throughout a product’s life cycle from raw material acquisition through production, use, end-of-life treatment and disposal (i.e. cradle-to-grave).*” (Society for Environmental Toxicology and Chemistry (SETAC) ).

International Organization for Standardization (2006) defined LCA as “*compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.*”.

The key points arising from these three quotations are consistent and show that LCA is used to assess the environmental impacts of a system under study. More importantly, these three definitions of LCA presented above emphasize that the environmental impacts associated with all stages in the system being studied need to be considered. In other words, LCA provides holistic environmental impact of the system under study. It helps to ensure that all possible environmental impacts in every stage in the system’s life cycle are taken into account. Its holistic feature assists LCA to be the effective tool used in environmental management. Thus, LCA is chosen to be used to analyse the environmental impact of steel & concrete in this research.

### **2.2.2 Development of LCA**

The concept of LCA has been used since the early seventies (Guinee 2002). However, in the past, the concept was called different names, such as Resources and Environmental Profile Analysis (REPA), Energy analysis or Product Eco-balance. LCA came to prominence in 1989. SETAC was the first international organization to develop the LCA approach (Guinee 2002). With its variety of members’ background, i.e. academia, industry and government, SETAC was able to provide a scientific based platform to LCA development. SETAC’s main aim has been to develop the technical framework for LCA.

International Organization for Standardization (ISO) has helped to refine the LCA approach. ISO began the development of LCA standards in 1994 (Guinee 2002). The ISO 14040 set of standards establishes a base for the approach relating to LCA.

Since this ISO 14040 set is part of the ISO 14000 - Environmental management series of standards - LCA is directly connected to the wide range of environmental management tools. While SETAC focuses on the development of the technical aspects of the LCA approach, ISO concerns both technical and organizational aspects, such as the critical review processes and the involvement of stakeholders.

The ISO LCA standards are shown below:

- ISO 14040: Life cycle assessment- Principles and framework
- ISO 14041: Life cycle assessment – Goal and scope definition and inventory analysis
- ISO 14042: Life cycle assessment – Life cycle impact assessment
- ISO 14043: Life cycle assessment – Life cycle interpretation
- ISO 14044: Life cycle assessment – Requirements and guidelines
- ISO 14049: Life cycle assessment – Example of application of ISO 14041 to goal and scope definition and inventory analysis

The ISO LCA standards mentioned above were established to provide a base line for implementation of LCA. The LCA study in this research has been conducted based on these ISO LCA standards.

### **2.2.3 Advantages of LCA**

Thomas (2005) discussed that the primary value of LCA is that it helps to ensure all possible environmental impacts which flow from all stages of a life cycle are identified. Similarly, Lundie and Peters (2005) discussed that LCA was developed to account for issues that are not identified by other environmental management tools.

It is also useful as a technique for comparing two or more alternative options in terms of their combined possible environmental impacts and ecological sustainability (Thomas 2005). Guinee (2002) claimed that the LCA approach helps to avoid ‘problem shifting’.

He further pointed out that it is important not to fix an environmental problem by shifting it to another stage in the life cycle of the product. For example, the use phase of product A may require less energy than product B. However, when considering the production phase of both products, processing of product A may consume larger amount of energy than that of product B. Thus, the environmental impacts from all stages of the alternative products should be taken into account before judging which product is more environmentally friendly than the other.

### 2.3 LCA Structure

The LCA study consists of four phases: goal definition, inventory analysis, impact assessment and interpretation. The following sections discuss the function of each stage in an LCA, and Figure 2.1 shows the relationship between these different stages.

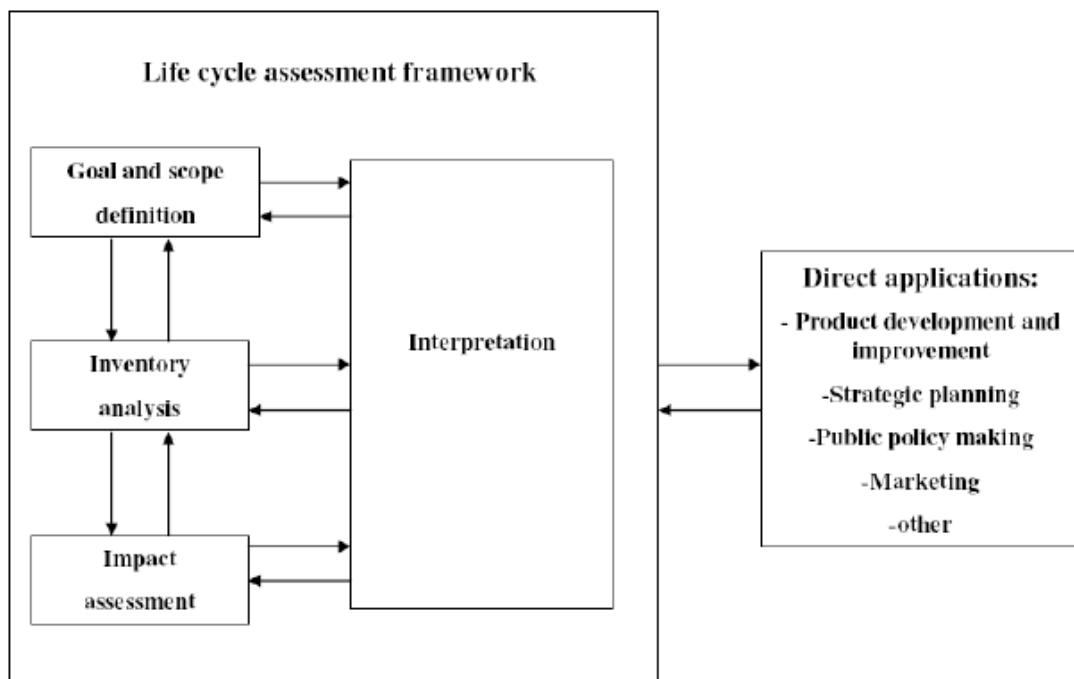


Figure 2.1 Stage of an LCA  
Source: International Organization for Standardization (2006)

### **2.3.1 Goal and scope definition**

In this phase, the goal of the study is set; the important decisions concerning boundary setting and the functional unit (reference unit) are defined. The goal of an LCA is set according to the intended application. To define the scope of an LCA study, the functions of the product/service being studied need to be clearly specified. These identified functions are used to define the functional unit. However, the functional unit set also needs to be consistent with the goal and scope of the LCA study. The functional unit is a quantification of the identified functions or performance characteristics of the product/service being studied (International Organization for Standardization 2000).

The functional unit is used as a reference when quantifying (in a mathematical sense) input and output data in the next stage (inventory analysis) of an LCA study. It was stated in ISO 14044 that the goal and scope of an LCA may need to be refined during the study, as unforeseen limitations, constraints and additional information might arise during the course of the LCA, affecting the original goal and scope set for the study (International Organization for Standardization 2006b).

### **2.3.2 Inventory analysis**

Allen & Rosselot (1997) identified that inventory analysis is the most important stage of an LCA application because it will impact on the remaining stages and the final result of the study. The data collected in this stage will be used in the life cycle impact assessment. In this stage, the information about the product/service system is collected and the relevant outputs and inputs, i.e. life cycle inventory (LCI) data, of the system being studied are quantified. The inputs and outputs collected in an LCA study include energy consumption, resources use, products, co-products and emissions. These inputs and outputs are quantified based on the functional unit set in the previous stage (goal and scope definition) of the LCA (International Organization for Standardization 2000).

To quantify the LCI data, assumptions often need to be made. It was suggested in ISO 14049 (Life cycle assessment – Example of application of ISO 14041 to goal and scope definition and inventory analysis) that any assumption or criteria used in the LCA study needs to be clearly described in this stage. This would help the LCA

practitioner to improve data quality during the course of the study. The International Organization for Standardization (2000) suggested that the initial LCI data should be collected using available (at the time of data collection) data. However, the data should be fully quantified during the course of the LCA (and subjected to sensitivity analysis) as there may be some additional information collected during the time of study which may help to improve the quality of the initial data collected.

***a) Attributional and Consequential LCI modelling***

After inventory analysis, the LCI data obtained are modelled in order to assess the environmental impacts of the system under study. The approach of LCI modelling is categorized into two methods; attributional method and consequential method. The terms attributional and consequential were first adopted in 2001 in the International Workshop on Electricity Data for Life Cycle Inventories, held in Cincinnati, Ohio (Curran et al. 2001; Ekvall & Weidema 2004). However, attributional/consequential LCI modelling approaches have been previously referred to by different terms, such as retrospective/prospective LCAs and accounting/changed-oriented LCAs, as documented in Tillman (2000) and Ekvall et al. (2005).

Curran et al. (2001) discussed that the distinction between these two LCI modelling approaches is that they respond to different questions. The attributional LCI modelling approach attempts to answer “*how are things (pollutants, resources, and exchanges among processes) flowing within the chosen temporal window?*” While the consequential LCI modelling approach attempts to answer “*how will flows change in response to decisions?*” Therefore, they suggested that the attributional model is appropriate to use if the LCI data are to be allocated or attributed to each product being produced in the economy at a given point in time (could mean past, present or future).

However, the consequential model is appropriate to use if the LCI data are to be used to estimate how the environmental flows of the system being studied will change as a result of the various potential decisions.

Tillman (2000) suggested that the choice of the LCI modelling approach to be used should be dependent on the goal and scope of the LCA study. For instance, in an LCA study intended to provide information to make a market claim (e.g.

environmental product declaration), attributional LCI modelling should be used. While in an LCA study to provide support information for decision making, the consequential LCI modelling may be more useful.

Ekvall (2003) stated that the attributional approach describes the environmental properties of a life cycle and its subsystem. Hence, the attributional LCI model includes the full life cycle of a system under study. It uses average LCI data and the data are allocated in proportion (e.g economic value). The consequential approach describes the effects of changes within the life cycle. Ekvall (2003) discussed that the consequential LCI model includes only the processes that are affected by changes. It uses the data which reflect the expected effects caused by changes. Moreover, it avoids allocation by means of system expansion (definition is described below).

#### ***b) System expansion***

System expansion is the technique used to help avoid co-production allocation in consequential LCI modelling. This is used when the process/system under study generates more than one product in the same process and the co-product(s) affect the processes outside the original system boundary set.

System expansion means the system boundary is expanded to cover alternative production of the exported functions (the functions of the co-product(s) in the original boundary system). In addition, other activities which are effected by the exported functions should be included (Ekvall & Finnveden 2001). This is undertaken in order to allow the options to be comparable in the comparative LCA study. Weidema (2001) have summarised the role of system expansion *as being “performed to maintain comparability of product systems in terms of product outputs through balancing a changes in output volume of a product that occurs in only one of the product systems, by adding an equivalent production in the other systems (or more elegantly and correctly by subtracting the equivalent production from the one system).”*

As consequential LCI modelling is performed to see how decisions made for the system under study will affect the environmental flows, system expansion is used in consequential LCI modelling. Ekvall & Weidema (2004) discussed that the aim of

consequential LCI modelling is to include what is affected by changes made to the system under study. Thus, they claimed that the processes outside the original system boundary set should also be included (through system expansion) since they are affected by the changes made in the system being studied.

### **2.3.3 Impact assessment**

The aim of this stage is to evaluate potential environmental impacts of the product/service system being studied using the LCI results obtained from the inventory analysis stage.

#### ***a) Mandatory impact assessment elements***

According to ISO 14044, life cycle impact assessment (LCIA) consists of four mandatory elements: selection of impact categories, category indicators and characterization models, assignment of LCI results to the selected impact categories (i.e. classification) and calculation of category indicator results (i.e. characterisation). These elements are discussed in the following sections.

#### ***1) Definitions of the terms related to LCIA used***

The definitions of the terms related to LCIA used in this section are listed below (International Organization for Standardization 2006):

- *Impact category is the class representing environmental issues of concern (e.g. environmental issues may include depletion of abiotic resources, climate change etc. Note that the main impact categories are described below).*
- *Impact category indicator is a quantifiable representation of an impact category (e.g. looking at climate change, infrared radiative forcing is an impact category, expressed as CO<sub>2</sub>-equivalent. Note that the impact indicator differs from category to category).*
- *Characterization model is the model used to convert the LCI results to the common unit of the category indicator (the common unit allows the calculation of the category indicator result) (e.g. considering climate change, the baseline model developed by the Intergovernmental Panel on Climate Change (IPCC) can be used as*

it defines the global warming potential of different greenhouse gases. Note that characterization models differ from category to category.)

- *Category endpoint is an attribute or aspect of the natural environment, human health or resources, identifying an environmental issue giving cause for concern* (e.g. the target endpoints of climate change impact category are coral reefs, forests and crops. Note that category endpoints differ from category to category (discussed in the following section)).

- *Environmental mechanism is the system of physical, chemical and biological processes for a given impact category, linking the life cycle inventory analysis results to category indicators and to category endpoints* (e.g. for climate change impact category, the greenhouse gases (LCI results) enhance radiative forcing which rises the temperature at the earth surface and this increased temperature (global warming) effects on ecosystems, human health and material welfare (category endpoints). Note that each impact category has its own environmental mechanism).

## **2) Definitions of impact categories**

Guinee (2002) defined baseline impact categories which are included in almost all LCA studies as depletion of abiotic resources, impact of land use, climate change, stratospheric ozone depletion, human toxicity, ecotoxicity, Photo-oxidant formation, acidification and eutrophication. However, it should be noted that different impact methods may use slightly different terms than the baseline impact categories described here (although having the same meaning). The definitions of the baseline impact categories described in Guinee (2002) are listed below:

*Depletion of abiotic resources* – is a depletion of natural resources (including energy resources) which are regarded as non-living such as iron ore, crude oil and wind energy.

This impact category is one of the most frequently discussed. Therefore, it has been interpreted differently in a wide range of impact assessment methods. Depending on the definition given to this impact category, some impact assessment methods only consider the impact of depletion of abiotic resources on natural environment, while some methods consider the impact of this impact category on both human health and natural environment (Guinee 2002).

*Impact of land use* – covers a range of consequences of human land use in different aspects such as resources, biodiversity and life function support, for example (Guinee 2002). The impacts of land use include both direct and indirect effects from occupation and transformation of land (Centre for Design 2008).

*Climate change* – is the impact of emissions caused by humans on the radiative forcing (i.e. heat radiation absorption) of the atmosphere. This is often referred to as the “greenhouse effect”. Greenhouse gas emissions increase radiative forcing which lead to an increase of temperature at the earth’s surface. This effect has impacts on ecosystems, human health and material welfare (Guinee 2002). It is one of the most discussed impact categories.

*Stratospheric ozone depletion* – is the thinning of the stratospheric ozone layer caused by emissions released by humans. When the stratospheric ozone layer becomes thinner, it means that a larger amount of solar UV-B radiation can reach the earth’s surface. The stratospheric ozone depletion has the potential to impact human health, the natural environment, the man-made environment and natural resources. For example, it may cause human skin cancer or damage to plants (Guinee 2002).

*Human toxicity* – covers the impacts on human health caused by toxic substances present in the environment. Guinee (2002) stated that the discussion on characterization of toxicity-related impact categories has not been yet settled. Therefore, this may cause high uncertainties across the LCA results obtained from the different impact assessment methods developed.

*Ecotoxicity* – covers the impacts on aquatic, terrestrial and sediment ecosystems caused by toxic substances present in the environment (Guinee 2002). Again, as mentioned above, characterization of toxicity-related impact categories have not yet been settled. Thus, there may be high uncertainties across the results (in this impact category) from different impact assessment methods.

*Photo-oxidant formation* – is the formation of reactive chemical compounds such as ozone, by the action of sunlight on certain primary air pollutants, including Volatile Organic Compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NO<sub>x</sub>). This photo-oxidant formation is also known as “summer smog”, distinct from “winter smog” in Europe, which is caused by inorganic compounds

such as particles, CO and sulphur compounds (Guinee 2002). The photo-oxidant formation may harm human health, causing conditions such as respiratory problems. In addition, it may harm the man-made environment, including the rubber industry. Haagen-Smith & Bradley (1953) reported that “summer smog” occurring in Los Angeles can cause severe rubber cracking. They further explained that this is caused by the release of high quantities of hydrocarbons into air with the presence of NO<sub>x</sub>. Moreover, it may cause damage to the natural environment, such as food crops and plankton.

*Acidification* – refers to the impacts on soil, ground water, surface water, biological organisms, ecosystems and materials (such as buildings) caused by acidifying pollutants such as SO<sub>2</sub> and NO<sub>x</sub> (Guinee 2002). The acidification problem is mainly seen in Scandinavian and European countries, for example, fish mortality in Scandinavian lakes and inefficient growth of softwood (e.g. spruce) forests, finally resulting in dieback (Centre for Design 2008).

*Eutrophication* – covers the impacts caused by excessively high levels of macronutrients present in the environment, such as Nitrogen and Phosphorus. For example, the excess nutrient enrichment may cause an undesirable shift in species composition, and may increase biomass production in both aquatic and terrestrial ecosystems. An increase of biomass in aquatic ecosystems may lead to a depressed oxygen level as additional oxygen consumption is required in biomass decomposition. Consequently, this may make surface water unacceptable as a source of drinking water (Guinee 2002). The main contributors to eutrophication are NO<sub>x</sub> contained in air emissions, storm water, waste water and agricultural runoff. These are the main nutrient sources which can cause eutrophication (Centre for Design 2008).

### ***3) Selection of impact categories***

It was stated in ISO 14044 that the chosen impact categories, category indicators and characterization models shall be consistent with the goal and scope of the LCA study. Moreover, they should be internationally accepted (International Organization for Standardization 2006). The selection of the impact categories to be examined needs to reflect the environmental issues concerned with the system being studied, taking into consideration the goal and scope of the study. For instance, an LCA study

to compare biomass based electricity generation and fossil fuel based electricity generation, needs to take into account the global warming impact category.

#### 4) Relation of the LCI results to the category indicator results

Figure 2.2 shows the relationship between the LCI results, category indicators and category endpoints, based on the environmental mechanism (using impact category “acidification” as an example). It is seen that the environmental mechanism links the LCI results to category indicators and to category endpoints respectively. However, it should be noted that each impact category has its own environmental mechanism (International Organization for Standardization 2006b).

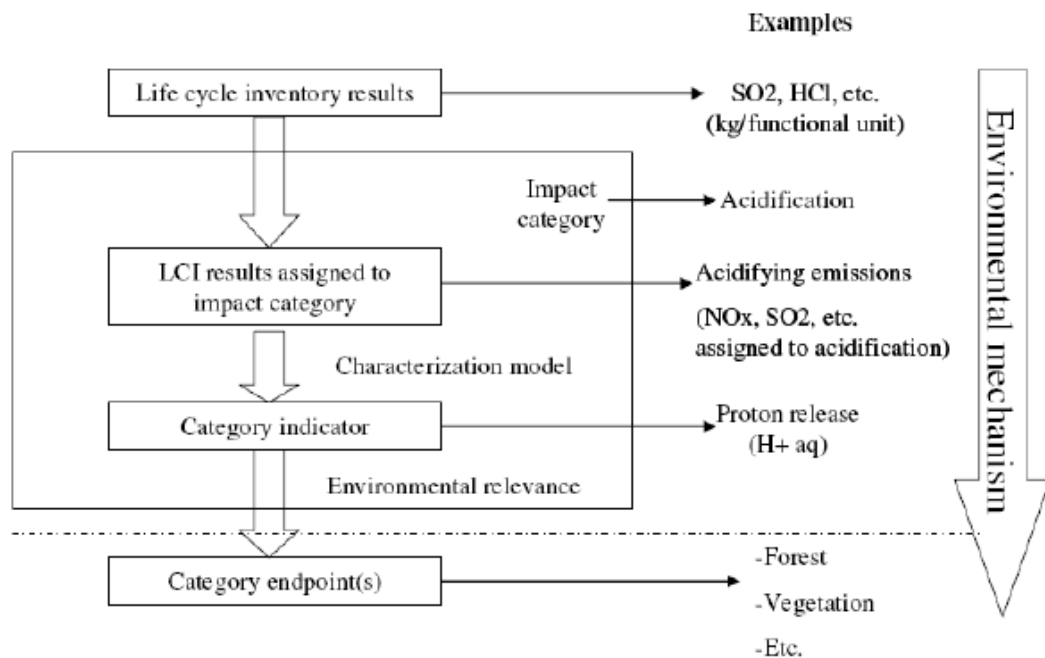


Figure 2.2 Concept of category indicators  
Source: International Organization for Standardization (2006)

The category indicator represents the quantity of environmental impact in different impact categories. Therefore, the impact indicator chosen for each impact category must be quantifiable. The category indicator occurs along the environmental mechanism. Thus, it can be chosen anywhere along the line between the LCI results and the category endpoints (International Organization for Standardization 2006). The characterization model is used to relate the LCI results to the category indicator.

ISO 14044 stated that the chosen characterization model to be used in an LCA study should be scientifically and technically valid. In addition, it should be internationally accepted (International Organization for Standardization 2006).

### ***b) Optional impact assessment elements***

The mandatory elements stated in ISO 14044 stops at the classification step, which yields impact indicator results for each selected impact category. This means that the impact indicator results of the selected impact categories have different units. This can make the interpretation of LCA results very difficult. Thus, there are optional steps such as normalization, grouping, weighting and data quality analysis, as described below (International Organization for Standardization 2006):

#### ***1) Normalization***

The International Organization for Standardization (2006) stated that “*Normalization is the calculation of the magnitude of the category indicator results relative to reference information (e.g. annual emission per capita). The aim of the normalization is to understand better the relative magnitude of each indicator result of the system under study*”. Normalization is undertaken by dividing an impact indicator result (of all impact categories) by a selected reference value (International Organization for Standardization 2006). In general, after normalization the results (i.e. normalized results) are dimensionless. However, this depends upon the unit of reference value used.

#### ***2) Grouping***

Grouping is the assignment of impact categories into one or more sets. This is undertaken based on the goal and scope set for the LCA study. The grouping may involve sorting impact categories (on a nominal basis) and ranking the impact categories in a given hierarchy. Therefore, the grouping is subjective as it is based on value choices. Different individuals or organizations may have different preferences (International Organization for Standardization 2006).

### **3) Weighting**

According to ISO 14044, weighting is defined as *“The process of converting the indicator results of different impact categories by using numerical factors based on values-choices. It may include aggregation of the weighted indicator results.”*

(International Organization for Standardization 2006). Thus, the weighting process is highly subjective based upon specific criteria chosen by LCA practitioners to give preference to certain environmental impact categories over others.

### **4) Additional LCIA data quality analysis**

Additional LCIA data quality analysis may be required to check the significance, uncertainty and sensitivity of the LCIA results. The data quality analysis uses specific techniques (e.g. uncertainty analysis and sensitivity analysis) to help in checking the results of LCIA. The results obtained from this analysis may lead to the revision of the LCI stage (International Organization for Standardization 2006).

As stated in the beginning of this section, normalization, grouping, weighting and data quality analysis are optional (according to ISO 14044). The need to perform these optional steps in an LCA study depends on the goal and scope set for the study.

### **c) Impact assessment methods**

Several organizations in different countries have developed multiple impact assessment methods which contain sets of indicators, as reviewed in Centre for Design. Examples of different impact assessment methods developed by researchers and scientists in various countries are shown in Table 2.1. The characterization model, normalization factors and weighting factors used in these different methods are only based on the conditions of the countries that developed the impact methods, and may not apply to other countries. However, there exists no country specific impact assessment methodology for India. Thus, the international methods will be selected for use to assess the environmental impacts of the selected building material. The selection of the impact methods to use depends on the goal and scope set for the LCA study.

Table 2.1 Examples of impact methods developed in different countries  
 Source: Centre for Design (2006; 2008)

Impact method	Country
EcoPoints	Switzerland
CML 1992 and 2000	The Netherlands
EPS 2000	Sweden
Eco-indicator 95 and 99	The Netherlands
Impact 2002	Switzerland
EDIP 2003	Denmark
LIME	Japan
Traci 2005	USA
ReCiPe 2008	The Netherlands

Some methods convert LCI results into impact indicators at midpoint level (the impact indicator occurs along an environmental mechanism, before the category endpoints). While some methods convert the LCI results to both midpoint and endpoint indicators.

Figure 2.3 shows an example of midpoint impact indicators and endpoint impact indicators, where it can be seen that the environmental mechanism links the LCI results to the midpoint impact indicators and consequently, to the endpoints. It was discussed in Centre for Design (2008) that the distinction between the results obtained at midpoint level (i.e. midpoint impact indicator results) are relatively robust compared with the endpoint impact indicator results. However, the interpretation of the results may be difficult. For this reason, the endpoint impact indicator results may facilitate the interpretation of the results as they are grouped and weighted into more limited categories (such as human health, ecosystem and resource consumption). Nevertheless, it should be noted that the endpoint impact indicator results are based on value-choices; different individuals or organizations may have different preferences. Therefore, this should be taken into consideration when interpreting the results.

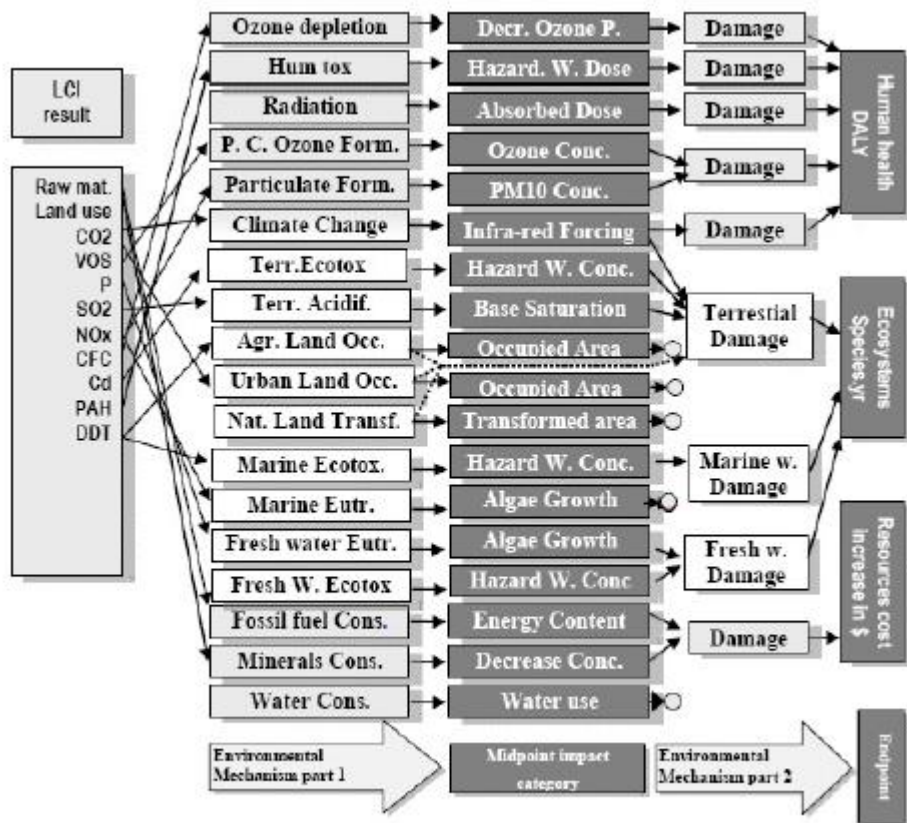


Figure 2.3 Example of midpoint impact indicators and endpoint impact indicators  
Source: Goedkoop et al. (2009)

### 2.3.4 Interpretation

The interpretation stage is when the findings of the inventory analysis and the impact assessment are combined to meet the previously defined goal of the study. The LCI and LCIA results are interpreted according to the goal and scope set for the LCA study.

According to ISO 14044, the life cycle interpretation stage comprises of the following steps (International Organization for Standardization 2006):

- Identification of the significant issues based on the results of the LCI and LCIA phases of LCA;
- An evaluation that considers completeness, sensitivity and consistency checks;
- Conclusions, limitations, and recommendation.

These steps are performed in order to understand the uncertainty of the final results. The interpretation stage normally includes data quality assessment and sensitivity analysis of the LCIA results. This information may provide a direction for revising the former stages of LCA to make them consistent with the goal and scope set for the LCA study.

In addition, it helps to identify the limitations of the LCA study when making conclusions and recommendations.

It should be emphasized that LCA is an iterative procedure. As discussed in the sections above regarding the stages of LCA application, the findings from one stage effect other stages. Therefore, it is important to go back and forth within the LCA framework (refer to Figure 4.1) to revise each stage (if necessary) in order to produce final results which are consistent with the goal and scope set.

#### **2.4 LCA and Structures**

Construction materials constitute a major percentage of the resources humans use today. The Worldwatch Institute estimates that world building construction is responsible for 40% of the stone, sand, and gravel, 40% of the energy, and 16% of the water used globally in 1999. Concrete buildings consume half of the European Union's the total energy and emit half its annual carbon dioxide production throughout their life cycles (Dimoudi and Tompa 2000). Although steel is a largely recyclable resource, it comes with high energy requirements. Construction materials such as concrete are more difficult to recycle, and as essentially nonrenewable resources they contribute more to total material consumption (Matos and Wagner 2001).

Because of numerous innovations reducing energy use during the operational phase of a building, the embodied energy due to a building's materials and construction is becoming a larger percentage of a building's total energy over its lifetime (Dimoudi and Tompa 2000). Therefore, it is essential to investigate the embodied energy of structures and determine ways to reduce this energy in the same way operational energy has already been reduced. This could be accomplished by changing the structural system of the building to use different or fewer construction materials. Life cycle assessment is an essential tool to help civil and structural engineers understand

how they can contribute to lowering the embodied energy of any structure. The potential for paradigm shifts in structural design due to the lessons learned from LCA could be significant.

LCA studies tend to focus either on residential structures or commercial structures. Because these two types of structure have different structural designs and energy consumption, it is important to study both separately; and because concrete and steel, along with timber, are the most heavily used structural materials, especially in commercial buildings, there is a great deal of dispute among researchers regarding which of these materials is more environmentally friendly (Carroll et al, Panarese, Weisenberger, and Worrell et al, to name a few).

The steel and concrete industries both campaign for the acceptance of their materials as the more sustainable choice, yet their research into this matter is not necessarily objective. A look at the range of studies performed on structures so far reveals biases, discrepancies in data, and inexplicable results. The numbers are even less credible for commercial structures because very few comparable studies have actually been performed. The question of concrete versus steel in commercial buildings requires more extensive, third-party research before it can be definitively answered.

## **2.5 LCA and Sustainability**

Environmental, economic, and social concerns are often described as the “triple bottom line” of sustainability and sustainable development (Hacking and Guthrie 77) (Figure 2.4). Any attempt toward true improvement in sustainability must consider all three pillars, not just one or two. LCA deals mainly with the environmental aspect of a product’s impact, and it is difficult or impossible to incorporate economic and social concerns in most cases (ISO 14040:2006). While cost can sometimes be quantified in impact assessment, it is not normally part of a life cycle inventory. Social issues are extremely broad and usually too qualitative to put in an LCA model; only those factors that can be quantified, such as a carcinogenic emission’s impact on human cancer rates, can be considered in impact assessment. Therefore, LCA presents only a partial picture of how a product may impact sustainability concerns from a truly holistic viewpoint.

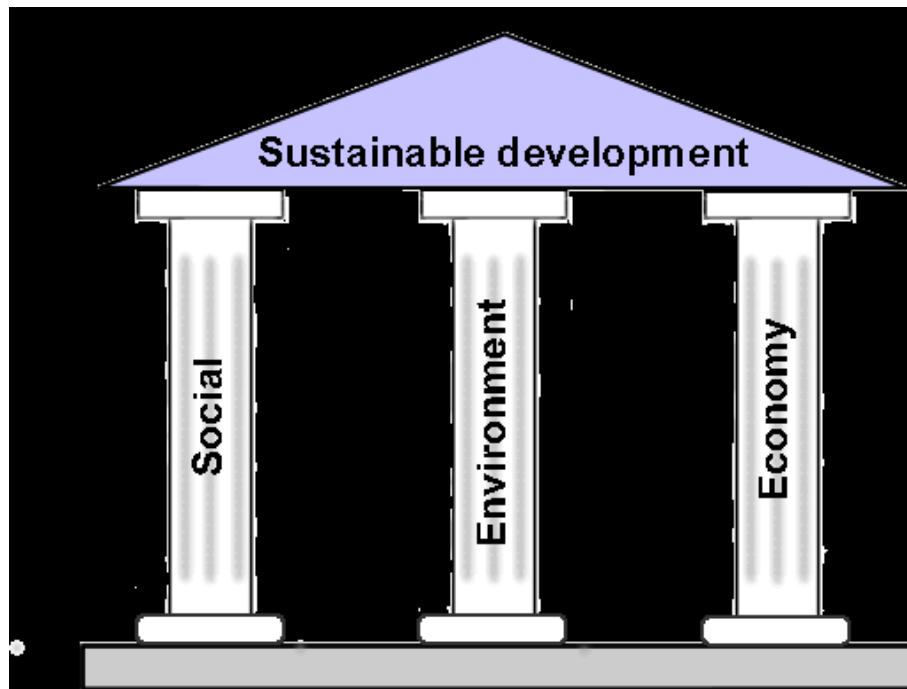


Figure 2.4: The Three Pillars of Sustainability.

(Source: <http://www.sustainability-ed.org>)

## 2.6 LCA software's packages

A range of LCA software packages have been developed, mostly in European countries. However, the leading software developed in those countries has become accepted and implemented worldwide. All LCA software packages developed have similar aims, which are to aid the users in the inventory stage of LCA. Some software packages also include the impact assessment function. In addition, some also include the inventory databases for some products and services.

Rice et al. (1997) compared twelve main European LCA software packages: Boustead(2), EcoPro 1.3, GaBi 2.0, KCL-ECO, LCAiT 2.0, LMS Eco-Inventory Tool, Oeko-Base, PEMS 3.0, PIA, SimaPro 3.1, SimaTool, ATHENA and TEAMTM/DEAMTM.

The chosen LCA software package used in this research is “**Athena Impact Estimator for Buildings**”. The Athena Impact Estimator is a whole building, life cycle based environmental assessment tool that lets building designers, product specifiers and policy analysts compare the relative environmental effects or trade-

offs across alternative building design solutions at the conceptual design stage. Some of the Impact Estimator's specific features include:

- the ability to model the building's complete structure and envelope (claddings, insulation, gypsum wall board, and roofing and window systems – over 1200 possible assembly combinations) over the expected life of a building;
- the ability to model maintenance and replacement life cycle effects based on building type, location and a user defined expected life for the building;
- a regionally sensitive calculator to convert operating energy to primary energy and emissions to allow users to compare embodied and operating energy environmental effects over the building's life (requires a separate estimate of operating energy as an input);
- an "end-of-life" module, which simulates demolition energy and final disposition of the materials incorporated in a building;

## **2.7 Applications of LCA**

Guinee (2002) commented that LCA has been used in both product development and wider applications, such as complex business strategies and government policies relating to consumption and life style choices. Examples of LCA applications in these two main areas are outlined below:

### ***Product development***

- LCA may be adopted to identify opportunities to improve the environmental performance of products at various points in their life cycle (International Organization for Standardization 2006).
- LCA may be used in an environmental comparison between existing products and the newly developed products (Guinee 2002).
- LCA can be involved in 'green' procurement, which is part of a 'green' purchasing policy (Guinee 2002). It can help to compare the environmental profiles of different choices of material/product to purchase.

- LCA can also be involved in marketing (e.g. an environmental claim, ecolabelling scheme or environmental product declaration) (International Organization for Standardization 2006). LCA is performed to provide the information required for assigning a 'green' label to products. This 'green' label enables consumers to make comparisons between products in terms of their environmental performances.
- LCA may be implemented in eco-design, which is the design of more environmentally friendly products (Guinee 2002). Information provided by LCA helps the designers to choose more environmentally friendly materials to use in the production process.

### ***Wider applications***

- Local governments could use LCA to compare the performances of the different approaches to waste management (Guinee 2002).
- An industry may apply LCA as a tool to prove to a government department that using one-way packaging causes less environmental burden than using re-usable packaging materials (Guinee 2002).
- The power industry may use LCA to compare the environmental benefits of different types of biomass to be used as a fuel in electricity production (Guinee 2002).
- LCA can help to provide information to make strategic plans for public investment in new infrastructure (Guinee 2002). For example, the transportation sector may use LCA to compare the environmental profiles of different modes of freight transport (i.e. road, rail and water).

From the examples of LCA applications mentioned above, it is seen that LCA has been found to be useful in a variety of applications, both in product development and wider applications such as strategic planning and policy making. Nevertheless, LCA also has its limitations, which need to be taken into consideration when adopting LCA in any application. The limitations of LCA are discussed in the following section.

## 2.8 Limitations of LCA

In spite of a number of its advantages, LCA also has limitations. Some limitations of LCA are outlined below:

- The implementation of LCA is expensive and time consuming (Tibor & Feldman 1996). This may be one of the barriers to using LCA for many companies or organizations.
- Data collection is always complicated and sometimes the data quality is poor. Tibor & Feldman (1996) commented that the LCA approach requires a variety of data resources. Data collection is difficult as some organizations do not always provide all data needed for LCA studies.
- LCA cannot address localized impacts. Guinee (2002) found that LCA does not provide a framework to identify the expected impacts caused by the functioning of a facility in a particular area.
- LCA provides steady-state (rather than dynamic) based results. Nevertheless, Guinee (2002) noted that, in the more detailed LCA studies, future technological developments are increasingly taken into account.
- LCA only focuses on the physical characteristics of the industrial activities and other economic processes; it does not take into account the market mechanisms or secondary effects on technological developments (Guinee 2002).
- LCA only focuses on the environmental aspects of the product/service under study; it does not take into account economic, social and other aspects (Guinee 2002). SETAC stated that *“LCA addresses environmental impacts of the system under study in the areas of ecological health, human health and resource depletion. It does not address economic considerations or social effects.”*
- LCA is not a purely scientific process, as it requires a number of technical assumptions, value judgments, and trade-offs (Guinee 2002; Tibor & Feldman 1996). However, Guinee (2002) commented that the ISO LCA standardization process (ISO 14040 series) has played an important role in helping LCA practitioners make the required assumptions as transparent as possible.

- LCA does not consider all relevant environmental impacts. Finnveden (2000) commented that since LCA does not cover all the relevant environmental impacts, only limited types of conclusions can be drawn from the LCA studies. In addition, Tibor & Feldman (1996) pointed out that the comparative LCA study (to choose one product over another) can be tricky as it may be misleading about all the possible environmental impacts included for one product against another. Thus, the assessment can lead to a wrong decision.

- Guinee (2002) discussed that although LCA can be used to provide supporting information for decision making, it cannot replace the decision making process itself. Therefore, additional evidence needs to be taken into consideration together with LCA results, before any decision can be made.

Though LCA is a very effective tool used to assess the environmental impacts of the system under study, it also has some limitations, as discussed above. These limitations need to be taken into account when making conclusions for an LCA study. For instance, Guinee (2002) noted that LCA can only provide supporting information for decision making. However, the decision made cannot be based entirely on LCA results, other evidence should be taken into consideration together with LCA results.

## Chapter 3

### Review of Existing Literature

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#### 3.1 Introduction

Performing life cycle assessments of construction materials is not a new concept. Because materials such as concrete and steel are used in massive quantities globally and their environmental impacts have long been a subject of interest. As far as commercial structures are concerned, however, research has been scattered and not always useful.

Table 3.1: Summary of Reviewed Studies.

Authors	Title	Year	Journal	Description
Eaton, K.J., and A. Amato	A Comparative LCA of Steel and Concrete Framed Office Buildings	1998	Journal of Constructional Steel Research	Five 4- and 8-story buildings
Junnila, Seppa, and Arpad Horvath	Life-Cycle Environmental Effects of an Office Building	2003	Journal of Infrastructure Systems	One 5-story, 15,600 m <sup>2</sup> building
Guggemos, Angela Acree, and Arpad Horvath	Comparison of Environmental Effects of Steel- and Concrete-Framed Buildings	2005	Journal of Infrastructure Systems	Two 5-story, 4400 m <sup>2</sup> buildings
Kofoworola, Oyeshola F., and Shabbit H. Gheewala	Life Cycle Energy Assessment of a Typical Office Building in Thailand	2009	Energy and Buildings	One 38-story, 60,000 m <sup>2</sup> building
Jönsson, Asa, Thomas Björklund, and Anne-Marie Tillman	LCA of Concrete and Steel Building Frames	1998	International Journal of LCA	Seven buildings, size unspecified
Cole, Raymond J., and Paul C. Kernan	Life-Cycle Energy Use in Office Buildings	1996	Building and Environment	Three 3-story, 4620 m <sup>2</sup> buildings
Johnson, Timothy Werner	Comparison of Environmental Impacts of Steel and Concrete as Building Materials	2006	N/A (MIT Thesis)	Two 100,000 ft <sup>2</sup> buildings, stories unspecified

What follows is a brief examination of seven prominent life cycle assessments performed on steel, concrete, and their application in commercial buildings.

Although most of the studies address the use and maintenance phases of a building, analysis of these sections is not included in the review because the focus of this study is on structure and construction. The papers, summarized in Table 3.1, have been chosen to represent a wide variety of goals and hypotheses, and this lack of continuity must be considered when analyzing their usefulness to a researcher who has a specific functional unit and scope in mind. They are being examined in order to determine how the research of building life cycles can be standardized and improved in future studies.

## **3.2 Studies**

### **3.2.1 Eaton & Amato (1998)**

Researchers at the Steel Construction Institute in the United Kingdom have produced a comprehensive life cycle assessment of steel and concrete office buildings. In this study focusing on the structural frames of typical buildings, the researchers analyzed their construction and operational phases, with attention given to the possibility of recycling the materials afterwards. Not only were both four- and eight-story buildings assessed for a 60-year lifespan, but each building was studied using five different structural systems, and there were also variations in the mechanical and HVAC systems investigated. Construction and demolition were omitted because of a lack of available data, and transportation emissions were calculated using UK averages.

A number of conclusions and suggestions for future study are made. The assessment shows that it is possible to include both embodied and operational energy and/or CO<sub>2</sub> of a building in a single LCA model, paving the way for future similar studies. Surprisingly, there is very little difference in emissions between steel and concrete framing in either building type, and the 8-story building, which uses a more complicated building design, has less embodied energy than the more basic 4-story building. Considering three steel and two concrete frame types, the embodied energy varies between just 2.5 and 2.9 GJ/m<sup>2</sup> for the 4-story building (Table 3.2). The embodied energy of the rest of the construction (HVAC, façade, etc.) is approximately 2.5 times that of the structural frame's embodied energy, and the total life cycle energy including use is 10-15 times higher than initial embodied energy for these buildings (Table 3.3). Operational energy consumption overtakes embodied

energy at anywhere from 4 to 11 years after building construction, depending on the ventilation systems used.

Table 3.2: Variation of embodied energy and carbon dioxide in 4-story structural systems. (Source: Eaton and Amato)

Type of structural system	Embodied energy (GJ/m <sup>2</sup> )	Embodied CO <sub>2</sub> (kg/m <sup>2</sup> )
Steel frame, Slimfloor beams, with precast concrete slabs	2.6	251
Steel frame, composite beams and slabs	2.6	241
In-situ reinforced concrete frame and slabs	2.5	286
Steel frame, cellular beams, and composite slabs	2.9	259
Concrete frame, precast concrete hollow core units	2.7	333

Table 3.3: Energy figures for steel-framed building with composite beams and slabs. (Source: Eaton and Amato.)

Contribution	Energy (GJ/m <sup>2</sup> )	CO <sub>2</sub> (kg/m <sup>2</sup> )
Initial embodied energy and CO <sub>2</sub> in the structural frame, floors, and foundations	2.6	241
Initial embodied energy and CO <sub>2</sub> in the rest of the structure	6.3	482
Other lifetime additions to embodied energy and CO <sub>2</sub> (refurbishment, etc.)	14.6	1091
Operational energy and CO <sub>2</sub> – lights and small power	33.6	2295
Operational energy and CO <sub>2</sub> – heating and ventilation	36.0	2239

The researchers stress that while concrete frames have slightly higher overall CO<sub>2</sub> emissions than steel frames, the variations found in the study are insignificant. Both steel and concrete frames perform up to UK standards for good building practice, and the supposed operational benefits of concrete construction due to its thermal properties do not appear to make a difference in the full LCA. Granted, the researchers have performed the study in order to “dispel myths that steel is not an environmentally friendly construction material,” and quantitative suggestions for reducing the energy of steel or concrete are not discussed. The main point they wish to make is that the embodied and operational energies of buildings can be further compared and reduced using LCA models. Although minor aspects of the building’s life cycle are left out, such as construction and disposal, this is the case with many

LCAs. Data simply is not available for many details of the life cycle process. One might think that these details add up to create a significant gap in the model, but because they are common to so many different models, they are often collectively ignored because of their insignificant energy contributions. This study excels at providing information in useful units of measurement. Embodied and operational energy consumption in the hypothetical office buildings is reported in either energy units of GJ/m<sup>2</sup> or carbon dioxide units of kg/m<sup>2</sup>. Reporting energy consumption and greenhouse gas emissions using a unit of area (square feet, square meters, etc.) is especially useful for construction applications; it allows the reader to instantly understand the environmental impact of any building or structure, regardless of its size, and buildings of different sizes can be compared using the same metric.

### **3.2.2 Junnila and Horvath (2003)**

These researchers from Finland and the United States published a life-cycle analysis of an office building in Finland. Their brief history of life-cycle assessment of buildings makes several apt comments about the state of LCA: "...it is still very difficult to find comprehensive information about the life-cycle aspects of offices." Residential buildings have been better-documented, and more information is needed about various types of office buildings. Additionally, "Building systems (structural, HVAC, electricity usage, and lighting) are rarely included [in LCAs], despite the fact that in practice most of the buildings are designed by building systems..." This LCA is of a single office building, so it does not involve comparison between two different types of structures. The structure consisted of three five-story sections that were all framed in cast-in-place concrete. The complex had a 50-year lifespan and an area of 15,600 square meters. The researchers were in a unique position to collect data about the material input and output flows in real time as the building was designed and constructed. They also gathered data from Finnish industry about emissions, which lacked only a few minor areas of data.

Life cycle assessment was performed in five phases corresponding to the most important stages of the building's life: building materials, construction, use, maintenance, and demolition. The model is by far the most comprehensive available on a single office building, including transportation between all phases. The phases were analyzed for their impact on five chemical equivalents that contribute to

environmental impact: climate change due to carbon dioxide, acidification due to sulfur dioxide (SO<sub>2</sub>), smog creation (H<sub>2</sub>C<sub>4</sub>), eutrophication due to phosphate (PO<sub>4</sub>), and heavy metals represented by lead (Pb) (Table 3.4). The table is further broken down into a two-page list detailing the contribution of each step in the construction, use, and disposal phases. For example, steel contributes to the most tons of CO<sub>2</sub>, kg of H<sub>2</sub>C<sub>4</sub>, and kg of Pb, while the concrete frame contributes to the most kg of SO<sub>2</sub> and PO<sub>4</sub>. It can also be deduced that the concrete for the frame makes up 65% of the total transportation weight for construction.

Table 3.4: Environmental Impacts of Office Building with 50 Years of Service Life.  
(Source: Junnila and Horvath)

Aspect of building	CO <sub>2</sub> (Tons)	SO <sub>2</sub> (kg)	H <sub>2</sub> C <sub>4</sub> (kg)	PO <sub>4</sub> (kg)	Pb (kg)
Building materials	4,800	19,000	7,600	1,900	7.4
Construction	820	5,800	530	960	0.3
Electrical service	25,000	59,000	4,900	5,500	3.8
Heating service	11,000	25,000	2,400	2,300	1.2
Other services	3,900	11,000	2,600	4,000	0
Maintenance	1,600	8,400	5,700	850	2.1
Demolition	440	4,400	680	720	0.3
<b>Total</b>	<b>48,000</b>	<b>130,000</b>	<b>24,000</b>	<b>16,000</b>	<b>15.0</b>

This study is an excellent example of what an LCA of a building should be. Data is explained and represented in several different ways to explain how units and phases can affect the numbers. The results are broken up into building components, such as structural, HVAC, and electrical, so that the impact due to the structural system can be easily deduced. In this case, the structural system contributed to climate change, smog, and heavy metal impacts more than any other component. The authors acknowledge that not much can be accomplished with the results from an LCA of just one building. Multiple building studies could allow a sensitivity analysis to see which components of the model vary the most from structure to structure. And because this building is in Finland, it cannot represent typical office buildings in India or any other continent. But the comprehensive tables created from the results could serve as a “checklist” for future LCAs or actual building projects. The data can also be trusted because it was completed during the building’s construction using firsthand reports, not after the fact when data may be less available or reliable.

### 3.2.3 Guggemos and Horvath (2005)

Arpad Horvath also collaborated with Angela Guggemos two years after the Finland study to perform LCAs of concrete and steel office buildings in the United States. Five-story office buildings with an area of 4400 m<sup>2</sup> were compared using steel and concrete frames at a hypothetical location in the Midwestern United States. Detailed flow charts were constructed to model the construction process for each frame type. A full building model was constructed, not just a structural frame. Transportation distances were assumed for that specific region, so as to model a typical Midwestern building as closely as possible.

The model was analyzed twice, once with respect to the full life cycle and once on the construction phase only. These two analyses are considerably different. Steel and concrete frames have results which are almost exactly the same for their full life cycles in terms of energy and several types of emissions (PM10 refers to particulate matter) (Table 3.5). Concrete emitted slightly more mono-nitrogen oxides (NO<sub>x</sub>), while steel emitted slightly more carbon monoxide and sulfur dioxide. Other emissions, most importantly carbon dioxide, were more or less equal for both. But concrete releases more emissions in the construction phase than steel (Figure 3.1: Steel vs. Concrete Frame Construction Phase Inventories.).

Table 3.5: Summary of Life Cycle Inventories.

(Source: Guggemos and Horvath)

<b>Structure</b>	<b>Energy (10 TJ)</b>	<b>CO<sub>2</sub> (Gg)</b>	<b>CO (Mg)</b>	<b>NO<sub>x</sub> (Mg)</b>	<b>PM10 (Mg)</b>	<b>SO<sub>2</sub> (Mg)</b>
Steel-frame building	36	26	38	72	9	100
Concrete-frame building	36	26	34	76	9	98

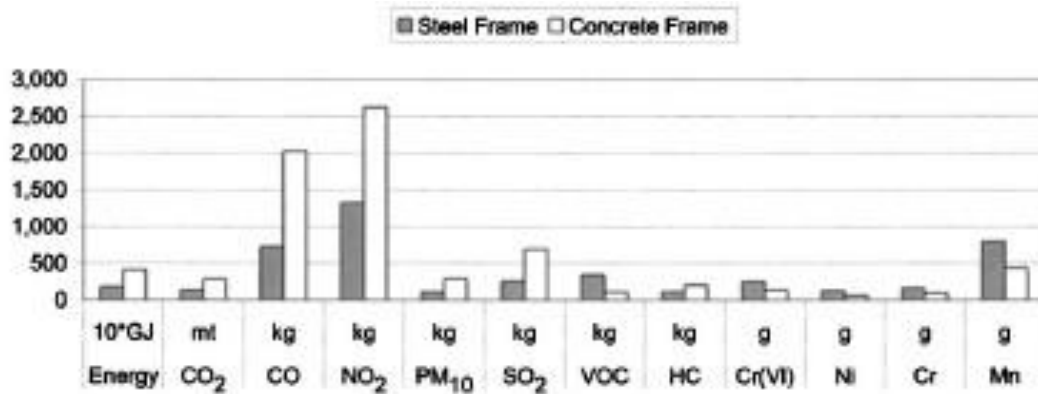


Figure 3.1: Steel vs. Concrete Frame Construction Phase Inventories.  
(Source: Guggemos and Horvath)

The authors also depict energy use at different stages of the life cycle, so that the relative impact of these phases can be compared to one another (Figure 3.2). However, the use phase of the building is not included, which is a major shortcoming because it is important to know how the materials and construction phases compare to the use phase. Although it was not investigated, there are clearly other aspects of the building's life cycle where steel causes more emissions than concrete. So while it is understood that concrete frames are more damaging to the environment due only to the material production, construction, and end-of-life phases, it is impossible to make a clear conclusion from this study about which material creates a more environmentally harmful building over its 50-year lifespan.

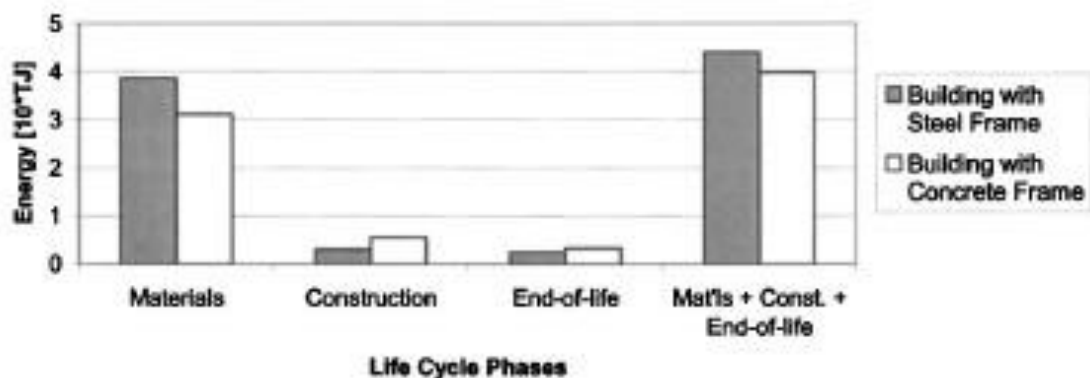


Figure 3.2: Comparison of Energy Impacts by Phase.  
(Source: Guggemos and Horvath)

A typical Midwestern office building obviously differs from a building in California, Massachusetts, or Hawaii. For a comprehensive study of office building energy use and emissions to be credible, these regional differences must be taken into account. Temperature and transportation distances are two of the most important factors that vary from region to region. This study is only so useful for someone assessing a building in a different region of the country, and a better study would compare buildings using a handful of regional variations. The authors compare their model to a similar Swedish study done in 1996 by Björklund et al. The Swedish numbers for a building's embodied energy are considerably smaller than the US buildings' embodied energy, and Björklund also found that concrete had more emissions than steel frames overall. While the Swedish study is older and there are probably inconsistencies in the data, the comparison illustrates how different United States studies can be from those in other parts of the world due to different practices and policies.

#### **3.2.4 Kofoworola and Gheewala (2009)**

This study focused on a recently erected 38-story, concrete-framed office building in Bangkok, Thailand. Instead of performing a traditional LCA, the researchers completed a life cycle energy analysis (LCEA), which focuses purely on energy use rather than emissions and other aspects of a full LCA model. The purpose of the study was to encourage updates to the Thai building code regarding energy use, and most of the paper focused on how energy can be reduced during the building's operational phase. However, the researchers also acknowledged that the embodied energy of the building after construction is second only to operational energy, and there are ways to reduce this embodied energy as well.

The data used for this study was Thailand-specific. Embodied energy of various building materials was obtained from databases maintained by the Thai government. An EIO-LCA methodology was used to obtain building material data, while process-based LCA methodologies were used for all other phases of the building's 50-year lifespan. The energy consumption according to phases in the building's life cycle is represented by a pie chart (Figure 3.3). "Manufacture" refers to the production and transportation of the raw materials, while "construction" refers to the assembly of the materials on site.

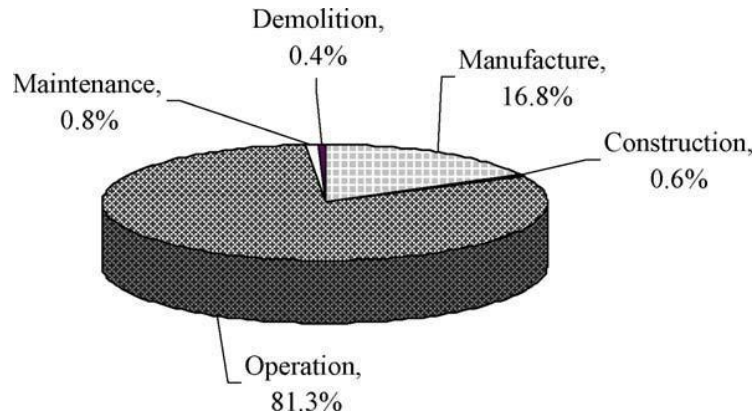


Figure 3.3: Distribution of the Energy Consumption by Phase.

(Source: Kofoworola and Gheewala)

Total embodied energy for the building was found to be 375 terajoules, corresponding to approximately 6.8 GJ/m<sup>2</sup>. Approximately 78% of this energy originated from the concrete and steel building materials (Figure 3.4), and this embodied energy corresponded to about 15% of the building’s operational energy over its projected lifetime. The embodied energy values computed in the study closely matched those of existing governmental data, and previous energy studies estimate a building’s embodied energy per square meter as ranging from 3.4-19.0 GJ/m<sup>2</sup>. The researchers attributed the building’s high embodied energy to the large quantities of material required to construct a reinforced concrete frame. Although it is not stated explicitly, a steel-framed structure would presumably use less material and have a lower embodied energy.

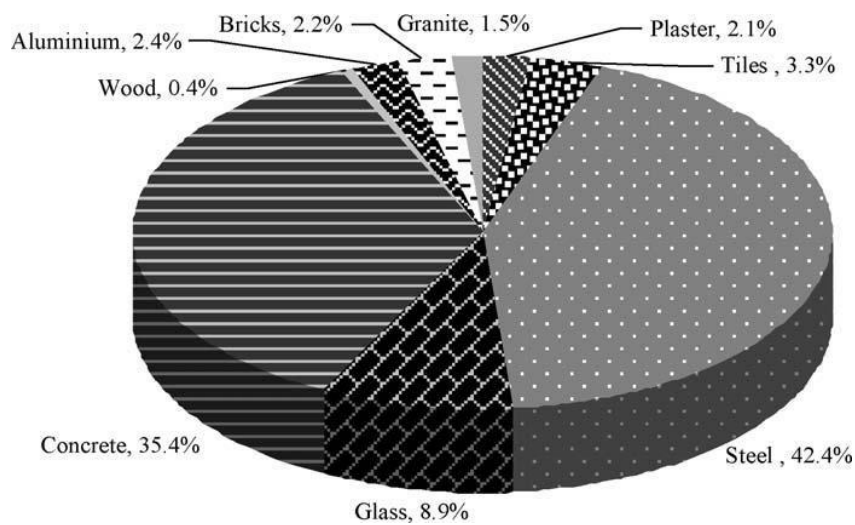


Figure 3.4: Material Percentage Share of Initial Embodied Energy.

(Source: Kofoworola and Gheewala)

Most of the author's discussion relates to reducing energy use through air conditioning methods and window space, but they devote some space to material recycling. Recycling steel and aluminum could reduce the building's embodied energy by 8.9%, corresponding to a total life cycle energy reduction of about 1.5%. This figure could be even higher if measures were taken to recycle the concrete as well. Current practices in Thailand dictate that concrete rubble be dumped in a landfill, but this rubble could be used in roads and other infrastructure. It was found that 9.2 GJ of energy could be saved if the rubble from this particular building were used as aggregate somewhere else, eliminating the need to produce new aggregate. This paper represents an in-depth study of a building's total energy use over its life, but it is not comprehensive enough because it does not examine greenhouse gas emissions or other environmental impacts. It also analyzes a single building that is not necessarily representative of all office buildings in its region.

### **3.2.5 Jönsson, Björklund, and Tillman (1998)**

Researchers in Sweden performed a full LCA, according to ISO guidelines, on seven hypothetical building frame types. According to the authors, "...the need to create systems models above the building material level to assess the environmental consequences of using alternative building elements and frame structures is generally recognized." Additionally, past research that they investigated indicated that there was no significant difference between concrete and steel frames. Their research showed otherwise. The following frame types were investigated:

- "In-situ cast concrete frame (office)
- "In-situ cast concrete frame (dwelling)
- "Precast concrete frame (office)
- "Precast concrete frame (dwelling)
- "Steel/concrete frame (office)
- "Steel/concrete frame (dwelling)
- "Steel/steel frame (dwelling)."

The functional unit was defined as a square meter of floor space, which is the most basic and adaptable functional unit for a building. Variations in building materials were accounted for, and the researchers strove to analyze average Swedish buildings, not the “best available technology.” The study encompassed only a comparison of the seven frame types as is, not how they could be improved.

The results of the inventory are displayed using a series of charts showing different impact categories, emphasizing that there is no one clear winner among the seven frames. One frame might use terms of CO<sub>2</sub>, NO<sub>x</sub>, sulfur oxides (SO<sub>x</sub>), chemical oxygen demand (COD), and hazardous and non-hazardous wastes. The operational energy use is also described both in and of itself, and by taking into account the embodied thermal savings of materials such as concrete.

A formal impact assessment is carried out using three established European methods—EPS, Environmental Themes, and Ecoscarcity—giving the reader a sense of how the results can be skewed or altered based on the differing parameters (Figure 3.5, Figure 3.6, and Figure 3.7). It also allows the reader to make the most important deductions about the study – for example, that Frame 7 has the highest environmental impact in all three methods. This study represents the most detailed and formal use of the ISO life cycle assessment guidelines.

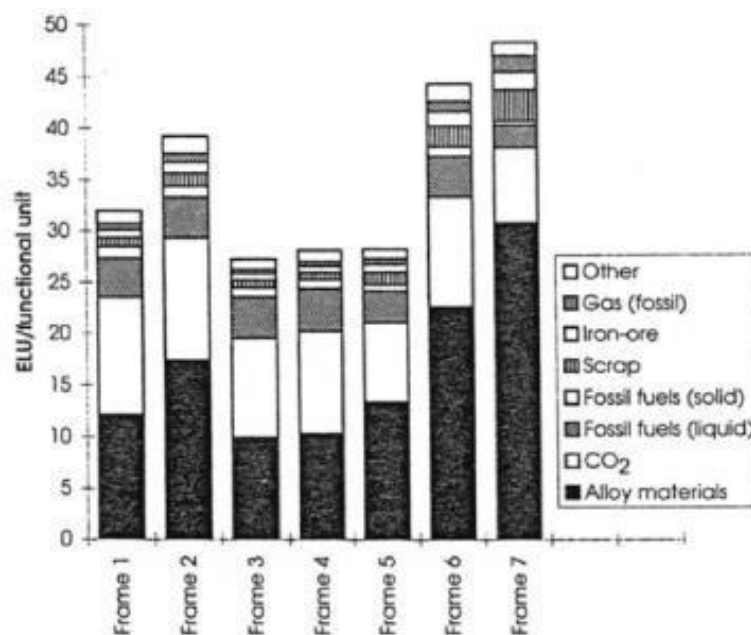


Figure 3.5: Environmental Impact Using the EPS Method.

(Source: Jönsson)

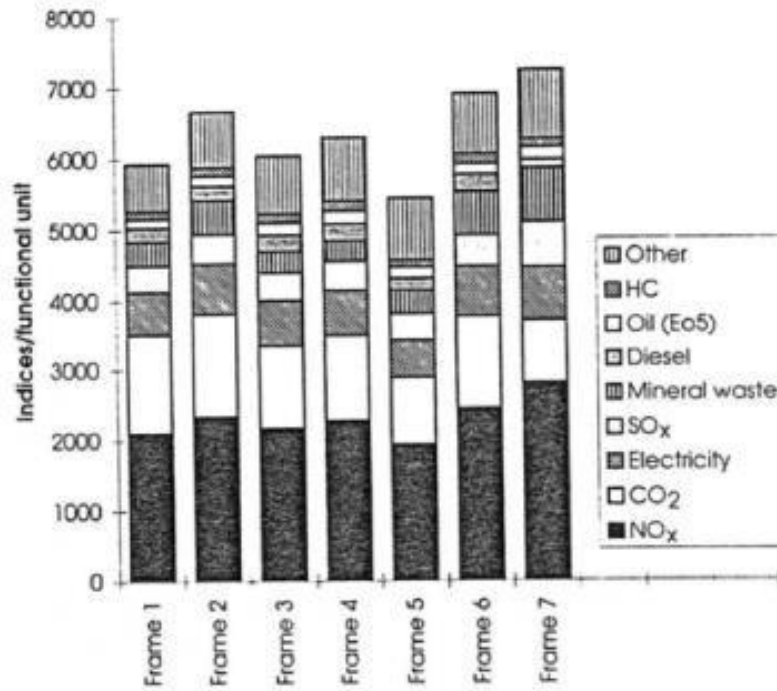


Figure 3.6: Environmental Impact Using the Environmental Themes Method.

(Source: Jönsson )

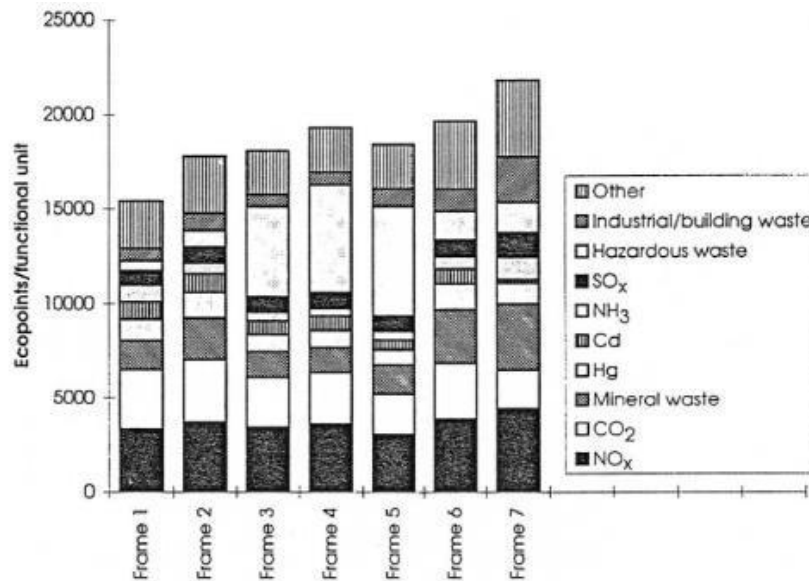


Figure 3.7: Environmental Impact Using the Ecoscarcity Method.

(Source: Jönsson)

### 3.2.6 Cole and Kernan (1996)

Performed with structures in Toronto and Vancouver in mind, this Canadian study analyzes the life-cycle energy use of hypothetical three-story office buildings framed

in wood, steel, and concrete, with and without underground parking garages. All results are reported for the overall building and in terms of  $\text{GJ}/\text{m}^2$  (Figure 3.8). In the case study, steel frames always have the highest embodied energy no matter how the data is manipulated, and wood frames the lowest. The parking garage increases the structure's embodied energy by 21-38%, depending on the frame material. The building envelope and the structure are always in first and second place for percentage of total embodied energy, but trade places depending on the type of material.

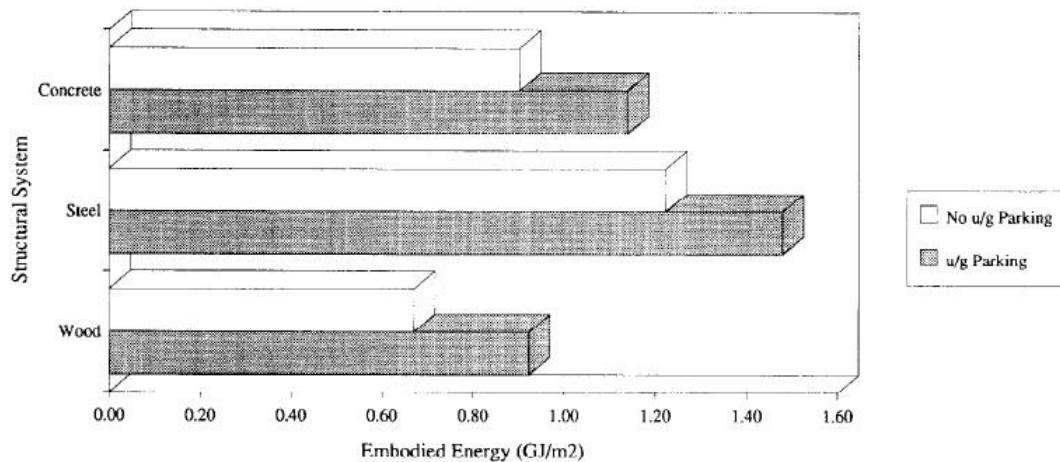


Figure 3.8: Embodied Energy of Structure.  
(Source: Cole and Kernan)

The authors also discuss the concept of “recurring” or “additional” embodied energy, which comes from replacing materials over the building’s lifetime. This recurring embodied energy can add up to a significant amount when the life of the building is extended from 25 years up to 50 or 100 years (Figure 3.9). The recurring embodied energy in a building with a 100-year lifespan may be two or three times larger than its initial embodied energy. One also cannot anticipate the changes in materials that may occur over the building’s lifetime, which may increase or decrease the embodied energy predicted today. The main conclusion, though, is that recurring embodied energy does not differ markedly between building materials, no matter what the building’s lifespan.

Despite the clear results stating that steel has the highest embodied energy, the authors are quick to point out that embodied energy can sometimes make up only 5%

of the building's total energy consumption over its lifetime, so the difference between structural materials becomes less significant in this light. The buildings sampled in the study also do not represent a broad enough range of office buildings in Canada to make definite conclusions about energy use per square meter in a typical building.

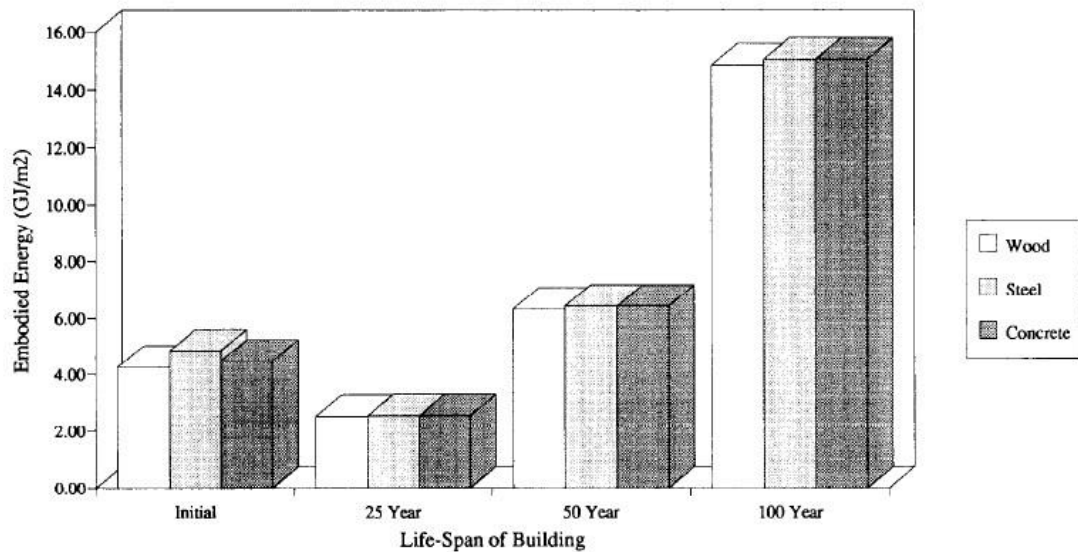


Figure 3.9: Recurring Embodied Energy (No Underground Parking).

Source: Cole and Kernan.

### 3.2.7 Johnson (2006)

Johnson performed a LCA study of concrete and steel building frames. He chose to analyze energy consumption, resource depletion, and carbon dioxide emissions, and compared embodied to operational energy of hypothetical structures. Johnson chose to analyze the concrete and steel required to construct a 100,000 square-foot building in Boston, Massachusetts. He considered this functional unit to be the smallest useful unit for those interested in sustainable design of commercial buildings. Although he assumed the building to be an office structure, he did not specify a number of stories, only the square footage. The system boundary included raw material extraction, production, manufacture, and construction phases only, not use or disposal phases. For this study Johnson uses the Ecoinvent database. Johnson used these numbers for his North American study due to a lack of better data. He did supplement Ecoinvent

data with personal fieldwork he conducted in the Boston area, mostly to understand the processes involved in steel and concrete production.

Johnson performs only minimal impact assessment because, as he writes, the inventory analysis speaks for itself. All three of his chosen environmental impact categories are within the same order of magnitude for both materials (Figure 3.10), although steel has fewer carbon dioxide emissions and less resource depletion than concrete (the two are virtually the same in terms of energy consumption). These values are converted into units per square foot (Table 3.6), and the difference in resource depletion becomes more noticeable, while the other two categories still show small or negligible differences.

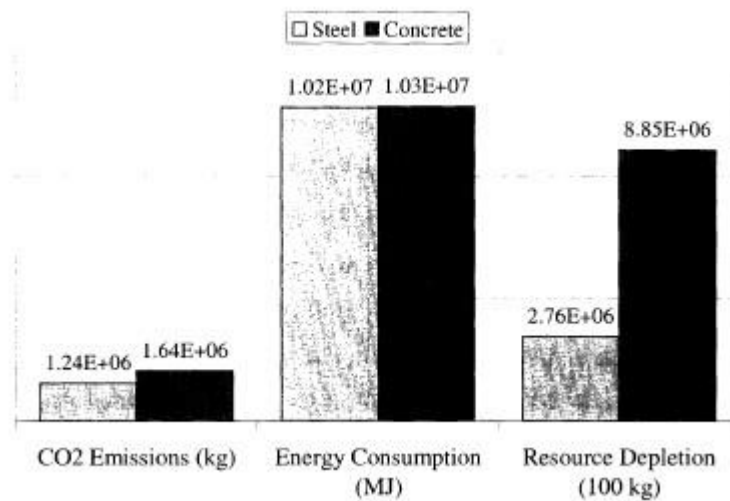


Figure 3.10: LCA Results in Three Impact Categories.

(Source: Johnson)

Table 3.6: LCA Results by Square Foot.

(Source: Johnson)

	CO <sub>2</sub> emissions	Energy Consumption	Resource Depletion
Steel	12.4 kg/SF	102.1 MJ/SF	2.8 Mg/SF
Concrete	16.4 kg/SF	102.5 MJ/SF	8.8 Mg/SF

Johnson also gives statistics on embodied energy, carbon dioxide, and resource depletion broken down by process and product for both materials. By examining past reports, he makes the conclusion that the differences in embodied energy between

the two materials are so small that it doesn't matter which is used. Operational energy is a more worthwhile area of study if one is interested in reducing energy use throughout a building's life cycle. He does, however, identify a need to reduce carbon dioxide emissions and resource use in concrete production. Steel wins in those two categories, while embodied energy is a draw.

This study describes steel and concrete manufacturing processes in detail based on personal interviews with New England industry. The model could also benefit from the use of computer software that would make data easier to condense and understand.

### 3.3 Variability in the Studies

Table 3.7 shows a comparison of the seven studies. The number of buildings included in the study is shown, along with whether the buildings exist in real life or are only ideal designs created by the researchers.

Table 3.7: Comparison of Reviewed Studies.

Study	Eaton & Amato	Junnila & Horvath	Guggemos & Horvath	Kofoworola & Gheewala	Jönsson et al	Cole & Kernan	Johnson
No. of buildings studied	10	1	2	1	7	6	2
Real or ideal?	Ideal	Real	Ideal	Real	Ideal	Ideal	Ideal
Country	UK	Finland	USA (Midwest)	Thailand (Bangkok)	Sweden	Canada (2 cities)	USA (Boston)
Units reported	GJ/m <sup>2</sup> kg-CO <sub>2</sub> /m <sup>2</sup>	MW-h kg matls kg CO <sub>2</sub> kg SO <sub>2</sub> kg H <sub>2</sub> C <sub>4</sub> kg PO <sub>4</sub> kg Pb	TJ Gg CO <sub>2</sub> Mg CO Mg NO <sub>x</sub> Mg PM <sub>10</sub> Mg SO <sub>2</sub>	TJ GJ/m <sup>2</sup>	kg matls MJ kg CO <sub>2</sub> kg NO <sub>x</sub> kg SO <sub>2</sub> COD/unit	GJ GJ/m <sup>2</sup>	kg CO <sub>2</sub> kg matls MJ kg CO <sub>2</sub> /ft <sup>2</sup> kg matls/ft <sup>2</sup> MJ/ft <sup>2</sup>
Full ISO LCA?	No	Yes	No	No; LCEA only	Yes	No	No; LCI only

The area of the world in which the buildings are sited is specified. The units that the researchers chose to report their findings are listed, whether they are units of mass, energy, or emissions. Finally, the table indicates whether the study followed formal ISO standards for an LCA or not. Although a study may be very comprehensive and provide useful information to the reader, LCAs that conform to ISO standards are accepted as the most valid. It is clear from the comparison that there is no consensus on which units should be measured for a full LCA of a structure. Two studies focus only on energy, while only one study incorporates waste masses into its impact assessment. Three studies measure emissions other than carbon dioxide in addition to the standard carbon dioxide equivalent measurement. Although some of these studies admit to covering only a portion of the full spectrum of LCA measurements available, such as the Thai study that performs only a life cycle energy assessment (LCEA), it is useless to compare these studies with others because of their different scopes.

An uncertainty analysis was performed to visualize the variability between these studies. Figure 3.11 and Figure 3.12 depict the analysis using two units, kilograms of carbon dioxide and gigajoules of embodied energy. In cases where the study encompasses more than one concrete or steel building, the number shown represents an average of the values for all concrete or steel buildings studied. The Kofoworola and Cole studies are omitted from Figure 3.11 because they do not report carbon dioxide emissions, and the Junnila study is omitted from Figure 3.11 because it does not report embodied energy. The Junnila study only reports carbon dioxide emissions for a concrete building, and the Kofoworola study only reports embodied energy for a concrete building, so steel values are not shown for these two studies. Otherwise, values from all the studies have been normalized into appropriate units for each graph. The graphs show some major differences between studies and make the variability even more obvious. Most notably, the steel values differ by almost an order of magnitude between the Guggemos and Jönsson studies for both carbon dioxide and embodied energy. It makes no sense that two of the most easily understandable metrics for quantifying LCA results produce such different results from study to study. But Johnson also compares his results to those of Guggemos and Horvath, and notes that the higher values in the Guggemos study are probably

due to “more comprehensive” data collection that includes materials such as foundations and cladding in its material considerations.

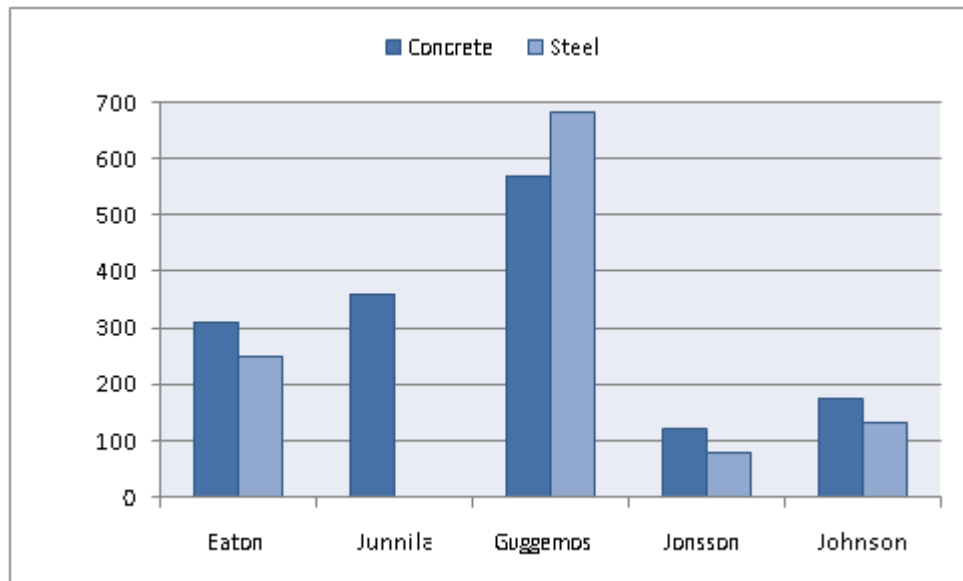


Figure 3.11: Carbon Dioxide Due to Materials and Construction in Reviewed Studies.

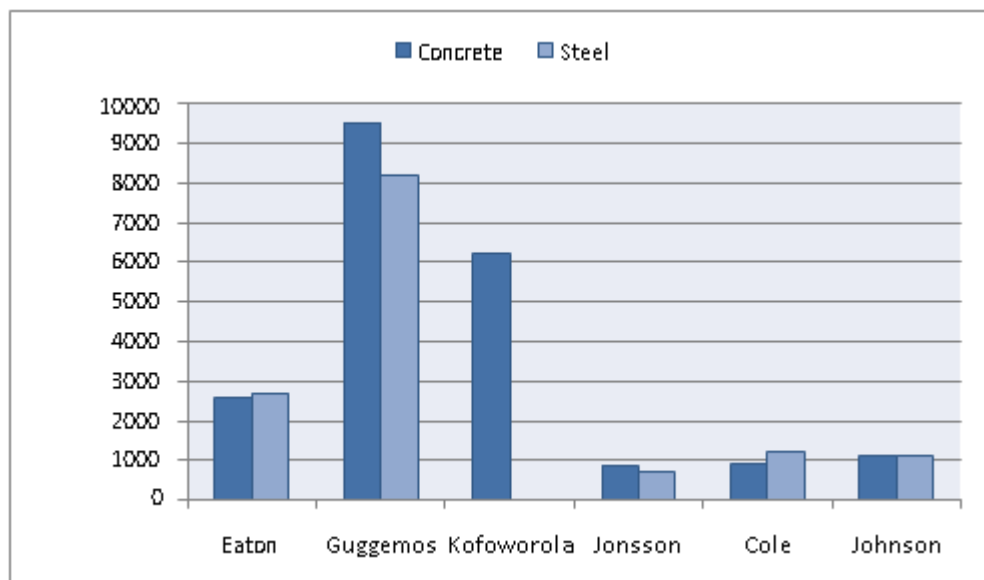


Figure 3.12: Embodied Energy in Reviewed Studies.

The size of the buildings varies in the studies, because the term “commercial building” is applied to a wide variety of structures which may have very little similarity to one another in size and function. Therefore, the carbon dioxide values

were converted again to represent kilograms of carbon dioxide per kilogram of material where possible (Figure 3.13), allowing global warming potential to be measured in a more basic unit that remains the same regardless of building size. The unit, named the carbon intensity factor (CIF), is dimensionless. Unfortunately, the building structures' approximate weights could be extrapolated only from the Junnila, Guggemos, and Johnson studies.

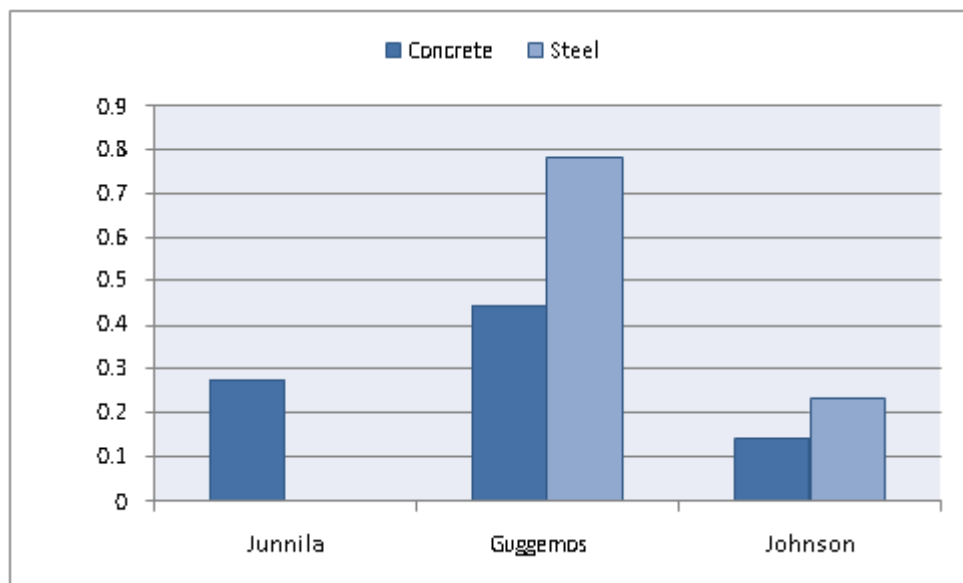


Figure 3.13: Carbon Intensity Factor, or Kilograms of Carbon Dioxide per Kilogram of Structural Material.

Because the Junnila study measures only a concrete building, the CIF of steel frames can be compared for just two of the studies. However, the CIF graph shows that the Guggemos study again has produced a much higher global warming potential than the other studies, regardless of material and unit conversion. It is not fully understood why this study varies so much from the others, but it illustrates the potential for variability in studies based on the system boundary and method of data collection. The functional units and reporting styles of these studies were so different from one another that compiling these graphs required extensive unit conversion.

### 3.4 Areas for Improvement

The seven studies described above represent some of the most detailed assessments of commercial buildings performed to date. The most important conclusion about the

body of work on commercial structures is that there is a major lack of research in India. More studies must be performed in the India that do not use data from other part of the world.

LCAs such as those reviewed in this section should have much broader scopes, in terms of the results they assess and the number and types of buildings they study. Life cycle inventories must use data that is accurate by country and region, and researchers should complete an impact assessment that covers a broad variety of impact categories which also apply specifically to the region of the world under study.

# Construction Process Description

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### 4.1 Concrete-Frame

The main product systems for the construction of concrete buildings are listed below:

- Concrete Production
- Formwork Production
- Reinforcing Bar Production
- Construction

The four product systems are discussed in greater detail in the next several sections. The detailed discussion includes a general process description of each system and then a specific discussion of data related to the functional unit.

#### 4.1.1 Concrete Production

Simply stated, the production of concrete involves the batching (or mixing) of all major inputs in a standard ratio. The major inputs of typical concrete include Portland cement, fine aggregate, coarse aggregate, water and additional admixtures (if required). Figure 4.1 depicts the major components of concrete.

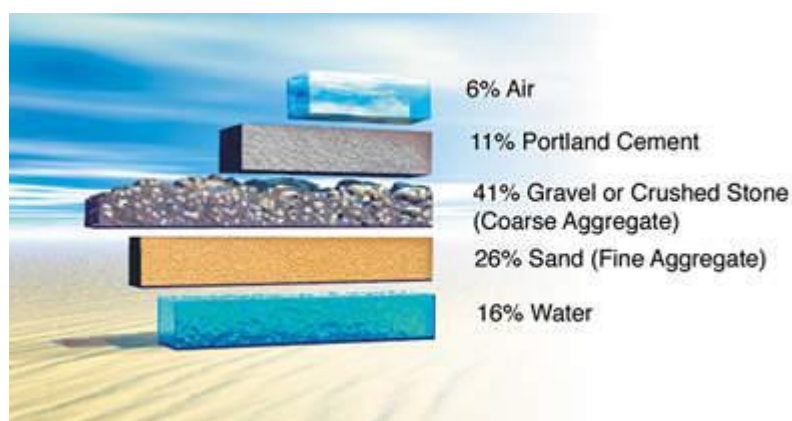


Figure 4.1. Typical Concrete Composition

Source: (PCA, 2011)

#### 4.1.1.1 Cement Production

The production of Portland cement is an essential component (sub-unit process) of concrete production. A graphic description of the overall process is shown in Figure 4.2.

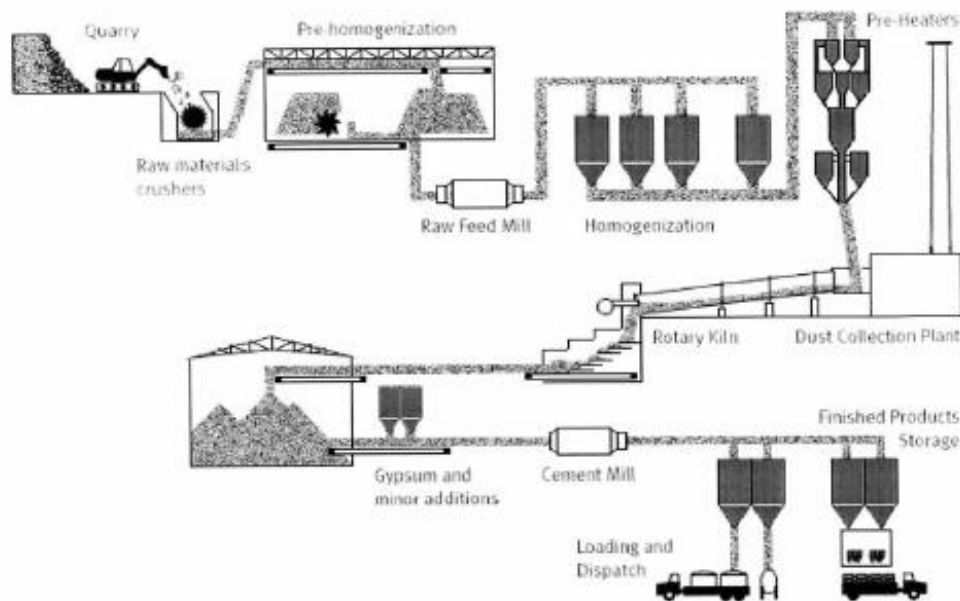


Figure 4.2. Cement Production Process

Source: (PCA, 2011)

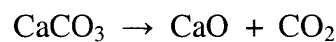
Raw materials including limestone, sand, and iron ores are extracted from quarries (see Table 4.1 for basic chemical components of cement), blended and crushed into a powder. This powder is then fed through a kiln, where the input raw materials are chemically combined under extreme heat (known as pyro-processing) into a material called clinker. The clinker is then cooled and ground with a small amount of gypsum into a very fine powder. This powder is Portland cement (PCA, 2006; ACI Educational Bulletin , 2011).

Table 4.1. Basic Chemical Components of Portland Cement

Source: (ACI Educational Bulletin, 2011)

Basic Chemical Components	Typical Raw Materials
Lime (CaO)	Limestone
Silica (SiO <sub>2</sub> )	Sand
Aluminum (Al <sub>2</sub> O <sub>3</sub> )	Shale, Clay, Bauxite
Iron (Fe <sub>2</sub> O <sub>3</sub> )	Shale, Clay, Iron Ore

Clinker production is the most energy intensive portion of this process with temperatures reaching over 1800° C. Because of this, Portland cement accounts for 94% of the energy used to produce concrete, but only accounts for 12% of the volume (Wilson, 1993). The pyro-processing also accounts for a large amount of CO<sub>2</sub> emitted as a by-product of calcination, which occurs in the kiln at roughly 900° C. Calcination is the chemical process where limestone (CaCO<sub>3</sub>) is converted to lime (CaO) and CO<sub>2</sub> at very high temperatures (Chaturvedi and Ochsendorf et al., 2004).



Estimates show that over 50% of the CO<sub>2</sub> emissions from cement production are due to the calcination process and the remaining is due to release of CO<sub>2</sub> during the burning of fossil fuels (Hendricks et al., 1998; Choate et al., 2003).

### 3.1.1.2 Aggregate Production

Aggregate required for concrete batching is divided into two categories;

- 1) Coarse aggregate (gravel/crushed rock)
- 2) Fine aggregate (sand).

The coarse aggregate is derived by extracting rock from quarries and iteratively crushing and sifting it to specific size. The fine aggregate is derived in a similar fashion and in some cases from the same process, with one or two additional production steps.

### **3.1.2 Formwork Production**

Formwork is a necessary and critical component of the cast-in-place concrete construction industry. Formwork are usually constructed of different types of plywood, but can also be made of plastic or steel.

### **3.1.3 Reinforcing Bar Production**

The third major component of any cast in place concrete job, besides the formwork and concrete, is the reinforcing bar (re-bar). Reinforcing steel bar is produced in steel bar mills. Typically, re-bar is available from local warehouses and distributors that stock typical sizes and lengths.

### **3.1.4 Construction**

A typical construction site involving cast in place concrete involves the integration of formwork placement, re-bar installation, and concrete pouring. These are all essential unit processes of any cast-in-place concrete construction project. The elementary flows considered for construction are primarily energy use (related to major equipment usage and power generation requirements on-site) and waste removal.

## **3.2 Steel-Frame**

The steel process flow was sub-divided into the six product systems listed below :

- Steel Beam Production
- Steel Connection Production
- Steel Fabrication
- Fireproofing Manufacture
- Concrete Production (for floor slabs)
- Construction

### **3.2.1 Steel Beam Production (Wide-Flange)**

This process is very energy intensive. Steel can be either cold formed or hot rolled into its standard shapes. All structural steel beams (wide-flange sections) are hot-rolled.

### **3.2.2 Steel Connection Production (Angle Section)**

Steel that is used for the production of connections are typically angle sections or plate steel. Most angles are produced using hot-rolling process. Typical steel connection sections used in steel fabrication are produced with a greater predictability than the steel wide-flange beams. This is due to the fact that fabricators rely on typical angle section sizes to fabricate the steel connections.

### **3.2.3 Steel Fabrication**

Steel fabrication, which involves the cutting, drilling and fitting of the raw steel members to meet the project specifications, is usually accomplished by a steel fabricator. Beam sections and connection sections are combined during this phase of the process flow, but have separate fabrication methods prior to being connected. The primary output from the steel fabrication shop is a 'combined member' ready for erection at the construction site.

### **3.2.4 Fireproofing Production**

There are two general types of steel fireproofing, intumescent paint and cementitious based spray-on fireproofing. In general, the spray-on fireproofing is used in the majority of steel buildings. This is mainly due to cost considerations because intumescent paints cost four times as much as traditional spray-on fireproofing.

### **3.2.5 Concrete Production**

An integral part of steel frame construction is the placement of concrete. Steel frames require a concrete floor slab system. In a typical floor slab only minimal reinforcement is required due to the composite action of the steel decking used to support the concrete floor slab.

### **3.2.6 Construction**

The main unit processes on a steel construction site are the erection of steel and the application of fireproofing. These processes are described in the following sections. The flows considered in this section are the energy consumed (in terms of equipment use) and waste removal.

## Chapter 5

### Defining the System Boundary

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#### 5.1 System Boundary

A critical step in the LCA method is defining the system boundary. Essentially, the system boundaries establish limits of the study and any process outside the boundary is ignored. The system boundary helps reduce the LCA to a manageable size by eliminating non-essential unit processes and elementary flows (Kotaji et al, 2003).

For improved clarity the system boundary will be defined in relationship to four major process flow stages. These stages are raw material extraction, initial production, finish material manufacture, and construction. All unit processes within each of these stages and the transportation requirements that link these stages are considered within the overall system boundary, unless otherwise noted. The system boundaries also include all elementary flows (both inputs and outputs) that relate to the environmental impacts that are the subject of this study. The included inputs are energy consumption and secondary natural resources, like water. The elementary flow outputs included in the system boundary are waste removal and harmful air emissions, specifically those that impact global warming. Air emissions that relate to human toxicity and acidification are also tracked as secondary effects. A graphic depiction of the system boundaries for both concrete and steel are shown in Figures 5.1 and 5.2, respectively. Exclusions from the system boundary will be defined in later sections.

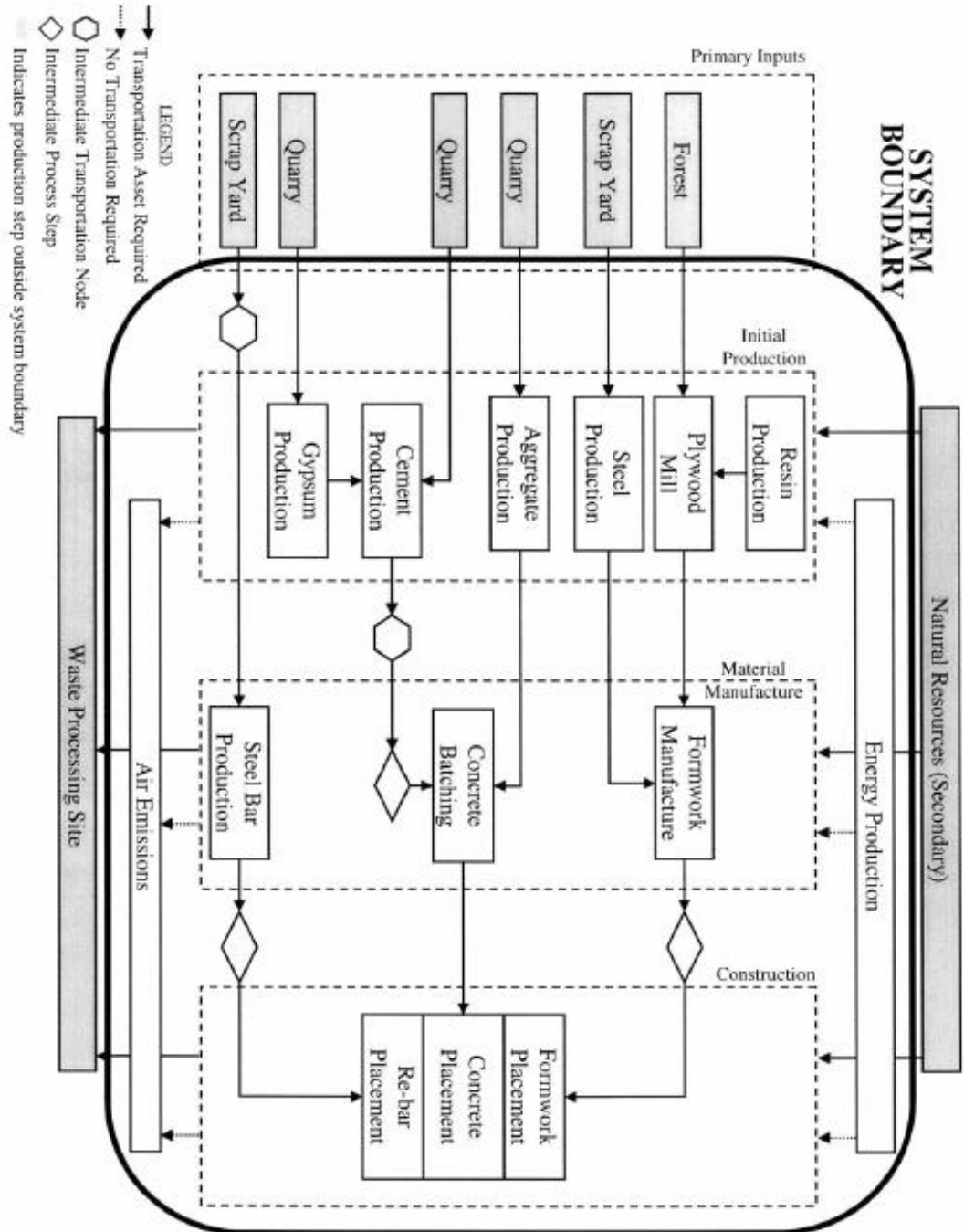


Figure 5.1. Concrete System Boundaries

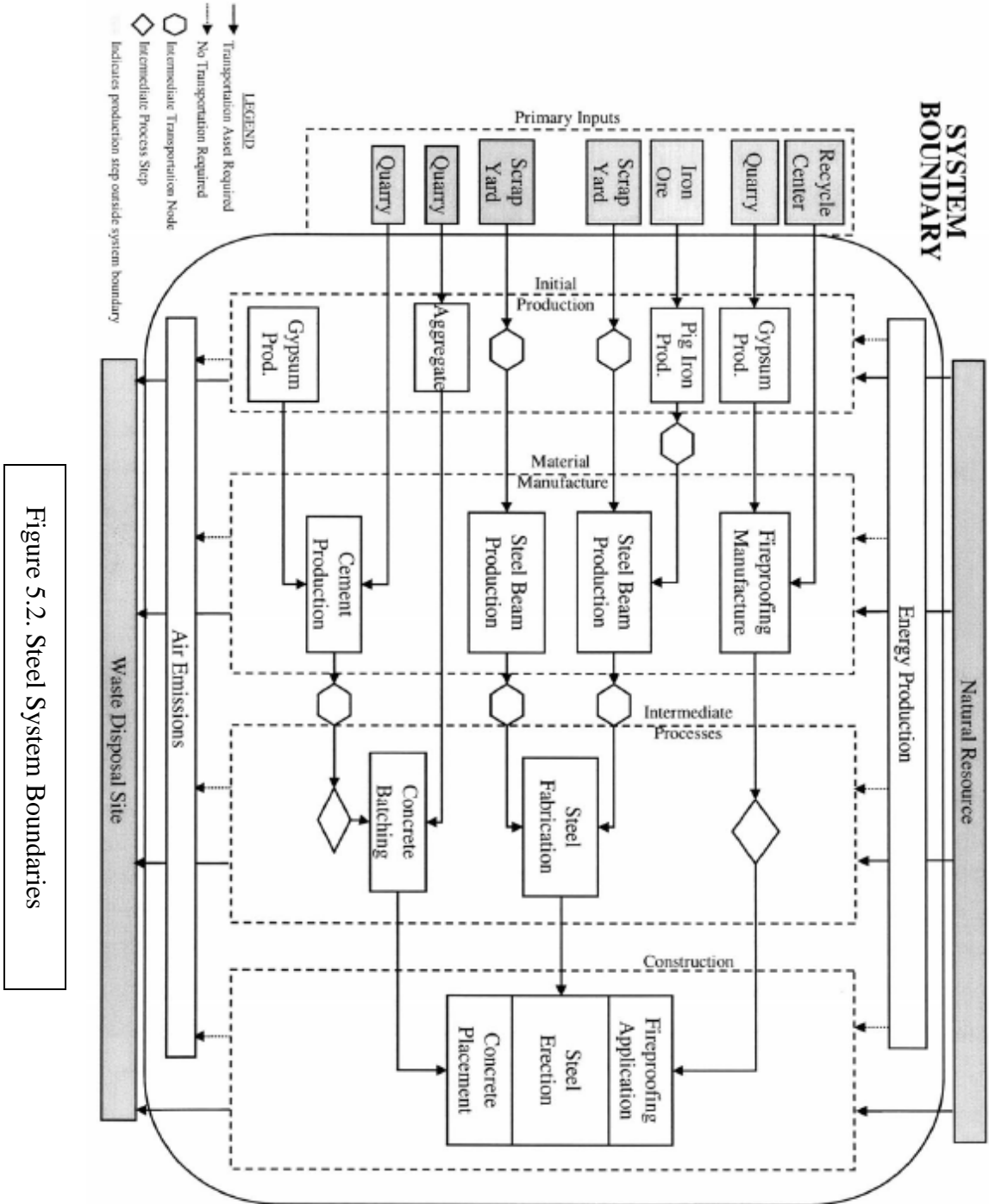


Figure 5.2. Steel System Boundaries

### **5.1.1 Raw Material Extraction**

The processes involved in raw material extraction are outside the system boundary. The system boundary begins at transportation from the extraction site to the initial production facility. For example, the transportation requirement from the quarry to the primary crusher at the cement production plant is included. The boundaries do not include the machinery (scooper/loader) or resources (blasting) to complete the actual extraction. In addition, the production processes at the local scrap yard, where scrap iron is collected for steel mills are not included, only the transportation from that scrap yard is within the system boundary. Clearly defined, the system boundary begins as the loaded transportation asset leaves the raw material extraction stage (quarry, mine, forest, gates of the scrap yard, etc.).

### **5.1.2 Initial Production**

The initial production processes are within the overall system boundary. These initial production facilities are where raw materials are turned into usable components. Refer to Figures 5.1 and 5.2 to identify the initial production unit processes for concrete and steel.

### **5.1.3 Material Manufacture**

The material manufacture stage is where usable materials are turned into finished materials for construction. The manufacturing unit processes for all direct and indirect product systems are included in the system boundary.

### **5.1.4 Construction**

On-site construction work is the final process flow stage. The system boundaries end at the erection of the functional unit at the construction site. The system boundary includes all elementary flows to and from this final stage, including the removal of all construction waste.

### **5.1.5 Transportation**

All transportation requirements between the four major stages are considered within the system boundary.

## 5.2 Process Inputs

- 1) **Primary inputs:** These inputs are those that are derived from the previous unit process. They are considered within the overall system boundary and serve as the direct link between two unit processes in the product system. In the case of the initial production stage, the primary inputs are either natural resources or recycled material.
- 2) **Energy Inputs:** All energy inputs that relate directly to the production process are included in the system boundary. The major energy inputs include electricity, natural gas, oil fuel, coal, and diesel.
- 3) **Secondary Natural Resources:** These are different than the primary inputs provided above. Secondary natural resource inputs include such raw materials as water and ancillary items that are not directly linked to an initial production facility as a raw resource input. These secondary natural resource inputs are included to capture total resource depletion quantities.

## 5.3 Process Outputs

- 1) **Finished product:** The finished product is within the system boundary and carries all relevant production and process data (on total air emissions, solid waste, etc.) to the next level in the process flow. The finished product from each unit process is within the system boundary and serves as the linkage to the next higher production step.
- 2) **Air emissions:** CO<sub>2</sub> emissions that relate to global warming are the main focus, in terms of air emission. Other harmful air emissions that lead to acidification and human toxicity are measured and included in the system boundary as a secondary focus. These air emissions are measured in kilograms per specific unit of production output (normally kilograms). The following table lists the air emissions considered and their impact on the environment.

Table 5.1. Harmful Air Emissions, by Type and Impact

Source: (UNEP, 1996)

Environmental Impact	Relevant Air Emission
Global Warming	CO <sub>2</sub> , Methane
Acidification	NO <sub>x</sub> , SO <sub>2</sub>
Human Toxicity	NO <sub>x</sub> , SO <sub>2</sub> , CO, Hg, Pb, Cd, Cr

**3) Waste removal:** Transportation of waste material from production facilities or intermediate facilities is included in the study. The transportation requirements are based solely on weight of all solid waste with final destination to landfill, recycling center, or municipal incinerator. Waste amounts are carried forward and disposed of at the product system level. This is done to simplify the inventory analysis without impacted the results.

## 5.4 System Boundary Exclusions

The system boundaries do not include the following:

- 1) Mining/Extraction:** It is important to remember that the actual mining and extraction operations at the quarry are not included but the material quantity ready for transport is used as the starting point for the overall system boundary.
- 2) Infrastructure:** The building, maintenance, and operation of necessary infrastructure, such as plant facilities and roads, are not included. It is assumed that infrastructure facilities are required for both materials and their impacts can be considered nearly equal and therefore negligible.
- 3) Worker commutes and manual labor issues:** Manual labor and impacts from workers are outside the system boundaries. While the transportation of worker crews to the site can add up to create significant impacts they are beyond the scope of this study.

- 4) **Non-production energy usage:** The energy used to heat and maintain facilities on a daily basis is excluded. This will be assumed equivalent between concrete and steel facilities.
- 5) **Land transformation and re-cultivation:** This study did not take into account land transformation and the impacts on the environment. For instance, the loss of woodland area due to the production of the formwork used in concrete construction is outside the boundary and not measured.
- 6) **Transportation of Secondary Raw Materials:** The delivery of secondary natural resources, such as water, is excluded.

## **6.1 Introduction**

The purpose of this LCA study is to compare the environmental impacts of steel and concrete when used as building materials. The comparison is made primarily through interpretation of raw data results. Normally, in the LCA methodology the next analytical step is to conduct an impact assessment. Impact assessment serves as a "tool for relating [multiple outcomes] of an inventory analysis to environmental problems.

The impact assessment displays results based on weighted values of contributing factors to the environmental hazards. The impact assessment step is used in this chapter as an analytical tool to compare environmental effects. Here we have limited our study to two ideal building structures; one is constructed using concrete as a material and other one as steel structure.

This study categorized main sources of data using Ecoinvent database and Athena Impact Estimator for Buildings. A major hurdle for many LCA research projects is the difficulty in data collection due to the lack of transparency in many production processes.

### **6.1.1 Reason for Use of Athena Impact Estimator for Buildings**

The Athena Impact Estimator database is used as the primary source of data for this study for several reasons; they are listed below.

- 1) **Completeness:** The database contained information on nearly all the unit processes involved with concrete and steel. All relevant data as it related to the LCA scope and intended purpose is included in the database.
- 2) **Equivalence:** The database allowed a baseline to be established instead of relying on separate and uncorrelated data sources for the different production

unit processes. This eliminates potential discrepancies between data points, in terms of time, measurement tools, and standard deviations.

- 3) **Availability:** The lack of data availability and transparency at the production level in the India, Athena Impact Estimator database is readily available and reliable source for data.

## 6.2 Assumptions for Use

This study assumes that the available data from European & North American countries is relevant to production processes. This is a large "leap of faith", but necessary and justifiable. This study makes no attempt to discuss production differences between the two continents because that is way beyond the scope of this study. Operational energy type and amount is considered constant for both buildings.

## 6.3 Functional Units

As discussed earlier for this comparative study to ideal buildings are chosen and their details are discussed in next section.

### 6.3.1 Concrete Building

It is an ideal concrete building and considered for comparative study of LCA. General information about this unit is mentioned in Table 6.1 and Bill of Material is presented in Appendix No. C1. However the values of structural detailing is shown in Appendix No. C2.

Table 6.1: General Information of Concrete Building

<b>Sr. No.</b>	<b>Specification</b>	<b>Description</b>
1	Building Type	Office Rental
2	Building Life Expectancy	60 years
3	Building Height	12m
4	Gross Floor Area	1620 mm <sup>2</sup>
5	No. of Stories	3
6	Operating Energy Type	Electricity, Diesel

### 6.3.2 Steel Building

Similar to Concrete Building it is also an ideal building and considered for comparative study of LCA. General information about this Steel Building is mentioned in Table No 6.2 and Bill of Material for the same is presented in Appendix No.S1. Values of structural detailing is shown in Appendix No. S2.

Table 6.2: General Information of Steel Building

Sr. No.	Specification	Description
1	Building Type	Office Rental
2	Building Life Expectancy	60 years
3	Building Height	12m
4	Gross Floor Area	1500 mm <sup>2</sup>
5	No. of Stories	3
6	Operating Energy Type	Electricity, Diesel

## 6.4 Analytical Results

Results for this case study is divided into three parts:

- 1) Calculation of Absolute Values individually for Life Cycle Assessment of both Concrete Building & Steel Building.
- 2) Summary of Life Cycle Stages for both building is calculated and discussed.
- 3) Comparative analysis of Concrete Building and Steel Building on the basis of eight environmental measures.

### 6.4.1 Absolute Values

These values are generated on the following parameters for both Concrete building and Steel building:

- Energy – total and primary energy consumed
- Air Emissions

- Water Emissions
- Land Emissions
- Ecologically Weighted Resource Use

#### **6.4.1.1 Energy – total and primary energy consumed**

Total energy consumption is a combination of energy requirements for all production facilities, transportation assets, and construction site demands across the overall process flow. These Values are shown in Appendix No. C3 for Concrete Building and in Appendix No. S3 for Steel Building.

#### **6.4.1.2 Air Emissions**

Harmful gases, pollutants & micro substances is released in almost all unit processes, either directly from a chemical reaction within the productions steps or through the burning of fossil fuels for kiln heating or to provide the electricity required to power the production facility. These values for Concrete and Steel Buildings are shown in Appendix No. C4 and Appendix No. S4 respectively.

#### **6.4.1.3 Water Emissions**

During various production steps substances believed to be harmful to animal and plant life in the aquatic environment and to human health is released. These substance either released with water or as waste product which later effects the quality of water. Absolute values related to water is shown in Appendix No. C5 for Concrete Building and in Appendix No. S5 for Steel Building.

#### **6.4.1.4 Land Emissions**

Apart from air emissions and water emissions, a significant amount of harmful substances are released as waste product. The Substances decrease the quality of soil to be used for agriculture or industrial use. Absolute values related to land emissions are shown in Appendix No. C6 for Concrete Building and Appendix no. S6 for Steel Building.

#### **6.4.1.5 Ecologically Weighted Resource Use**

Under this Absolute value the use of Ecological resource are assessed. These values measure negative environmental impacts related to natural resource use by industry. Appendix No. C7 shows results for Concrete Building whereas Appendix No. S7 shows results for Steel Building.

#### **6.4.2 Summary**

In this section summary for both buildings is shown for Life Cycle Stages, which displays material and transportation effects in each life cycle stages.

##### **6.4.2.1 Concrete Building Related Summary**

In this section overall summary of Life Cycle Stages for Concrete building is calculated. These values are shown in Table 6.3.

##### **6.4.2.2 Steel Building Related Summary**

In this section overall summary of Life Cycle Stages for Concrete building is calculated. These values are shown in Table 6.4.

**Table 6.3 Detailed Summary Measure Table by Life Cycle Stages Concrete Building.**

Summary Measure	Unit	PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)			END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)		TOTAL EFFECTS			
		Manufacturing	Transport	Total	Construction-Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
Global Warming Potential	kg CO2 eq	2.27E+05	8.80E+03	<b>2.86E+05</b>	1.90E+04	1.33E+04	<b>3.24E+04</b>	8.65E+03	2.28E+02	4.83E+05	<b>4.92E+05</b>	1.06E+04	5.32E+03	<b>1.59E+04</b>	3.37E+04	0.00E+00	<b>3.37E+04</b>	<b>8.25E+05</b>	<b>8.59E+05</b>
Acidification Potential	kg SO2 eq	1.27E+03	8.15E+01	<b>1.35E+03</b>	1.23E+02	1.24E+02	<b>2.47E+02</b>	7.91E+01	2.28E+00	3.11E+03	<b>3.19E+03</b>	1.28E+02	4.80E+01	<b>1.76E+02</b>	7.82E+01	0.00E+00	<b>7.82E+01</b>	<b>4.97E+03</b>	<b>5.05E+03</b>
H1I Particulate	kg PM2.5 eq	7.55E+02	4.78E+00	<b>7.59E+02</b>	2.77E+01	7.30E+00	<b>3.50E+01</b>	2.70E+01	1.28E+01	3.53E+02	<b>3.80E+02</b>	8.74E+00	2.88E+00	<b>1.16E+01</b>	3.42E+01	0.00E+00	<b>3.42E+01</b>	<b>1.19E+03</b>	<b>1.22E+03</b>
Eutrophication Potential	kg N eq	3.17E+01	5.56E+00	<b>3.73E+01</b>	5.79E+00	8.47E+00	<b>1.43E+01</b>	2.13E+01	1.55E+01	3.40E+01	<b>5.55E+01</b>	8.01E+00	3.28E+00	<b>1.13E+01</b>	4.01E+00	0.00E+00	<b>4.01E+00</b>	<b>1.18E+02</b>	<b>1.22E+02</b>
Ozone Depletion Potential	kg CFC-11 eq	2.28E-03	3.21E-07	<b>2.28E-03</b>	1.13E-04	4.92E-07	<b>1.13E-04</b>	1.60E-04	8.93E-09	4.12E-06	<b>1.64E-04</b>	4.08E-07	1.91E-07	<b>5.99E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.56E-03</b>	<b>2.56E-03</b>
Smog Potential	kg O3 eq	1.48E+04	2.83E+03	<b>1.77E+04</b>	3.19E+03	4.31E+03	<b>7.51E+03</b>	6.11E+02	7.94E+01	1.32E+04	<b>1.39E+04</b>	4.24E+03	1.67E+03	<b>5.91E+03</b>	7.89E+02	0.00E+00	<b>7.89E+02</b>	<b>4.50E+04</b>	<b>4.58E+04</b>
Total Primary Energy	MJ	3.10E+06	1.14E+05	<b>3.21E+06</b>	2.09E+05	1.67E+05	<b>3.76E+05</b>	4.20E+05	3.04E+03	7.37E+06	<b>7.79E+06</b>	1.59E+05	6.50E+04	<b>2.24E+05</b>	1.56E+05	0.00E+00	<b>1.56E+05</b>	<b>1.16E+07</b>	<b>1.18E+07</b>
Non-Renewable Energy	MJ	3.07E+06	1.14E+05	<b>3.18E+06</b>	2.08E+05	1.67E+05	<b>3.75E+05</b>	4.02E+05	3.04E+03	7.08E+06	<b>7.49E+06</b>	1.58E+05	6.50E+04	<b>2.23E+05</b>	1.56E+05	0.00E+00	<b>1.56E+05</b>	<b>1.13E+07</b>	<b>1.14E+07</b>
Fossil Fuel Consumption	MJ	2.24E+06	1.13E+05	<b>2.36E+06</b>	1.97E+05	1.66E+05	<b>3.63E+05</b>	8.96E+04	3.03E+03	6.24E+06	<b>6.34E+06</b>	1.55E+05	6.48E+04	<b>2.20E+05</b>	3.14E+05	0.00E+00	<b>3.14E+05</b>	<b>9.28E+06</b>	<b>9.59E+06</b>

**Table 6.4 Detailed Summary Measure Table by Life Cycle Stages Steel Building.**

Summary Measure	Unit	PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)			END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS		
		Manufacturing	Transport	Total	Construction- Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
Global Warming Potential	kg CO2 eq	2.57E+05	5.81E+03	<b>2.63E+05</b>	9.24E+03	2.03E+04	<b>2.95E+04</b>	8.55E+03	2.28E+02	4.83E+05	<b>4.92E+05</b>	1.22E+04	2.83E+03	<b>1.51E+04</b>	-4.49E+03	0.00E+00	<b>-4.49E+03</b>	<b>7.99E+05</b>	<b>7.95E+05</b>
Acidification Potential	kg SO2 eq	1.23E+03	5.37E+01	<b>1.28E+03</b>	8.10E+01	2.05E+02	<b>2.86E+02</b>	7.91E+01	2.28E+00	3.11E+03	<b>3.19E+03</b>	1.30E+02	2.56E+01	<b>1.55E+02</b>	1.12E+01	0.00E+00	<b>1.12E+01</b>	<b>4.92E+03</b>	<b>4.93E+03</b>
HH Particulate	kg PM2.5 eq	7.15E+02	3.15E+00	<b>7.19E+02</b>	1.75E+01	1.14E+01	<b>2.89E+01</b>	2.70E+01	1.28E+01	3.53E+02	<b>3.80E+02</b>	1.69E+01	1.53E+00	<b>1.84E+01</b>	4.90E+00	0.00E+00	<b>4.90E+00</b>	<b>1.15E+03</b>	<b>1.15E+03</b>
Eutrophication Potential	kg N eq	3.87E+01	3.67E+00	<b>4.24E+01</b>	4.28E+00	1.39E+01	<b>1.82E+01</b>	2.13E+01	1.55E+01	3.40E+01	<b>5.55E+01</b>	7.32E+00	1.75E+00	<b>9.06E+00</b>	5.74E+01	0.00E+00	<b>5.74E+01</b>	<b>1.25E+02</b>	<b>1.26E+02</b>
Ozone Depletion Potential	kg CFC-11 eq	1.26E-03	2.12E-07	<b>1.26E-03</b>	5.53E-05	8.04E-07	<b>5.61E-05</b>	1.60E-04	8.93E-09	4.12E-06	<b>1.64E-04</b>	3.99E-07	1.02E-07	<b>5.01E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.48E-03</b>	<b>1.48E-03</b>
Smog Potential	kg O3 eq	1.52E+04	1.87E+03	<b>1.71E+04</b>	2.21E+03	7.13E+03	<b>9.34E+03</b>	6.11E+02	7.94E+01	1.32E+04	<b>1.39E+04</b>	3.84E+03	8.88E+02	<b>4.73E+03</b>	1.15E+02	0.00E+00	<b>1.15E+02</b>	<b>4.50E+04</b>	<b>4.52E+04</b>
Total Primary Energy	MJ	3.72E+06	7.45E+04	<b>3.79E+06</b>	1.22E+05	2.69E+05	<b>3.90E+05</b>	4.20E+05	3.04E+03	7.37E+06	<b>7.79E+06</b>	1.86E+05	3.46E+04	<b>2.20E+05</b>	2.24E+04	0.00E+00	<b>2.24E+04</b>	<b>1.22E+07</b>	<b>1.22E+07</b>
Non-Renewable Energy	MJ	3.62E+06	7.45E+04	<b>3.69E+06</b>	1.18E+05	2.68E+05	<b>3.86E+05</b>	4.10E+05	3.04E+03	7.08E+06	<b>7.49E+06</b>	1.83E+05	3.46E+04	<b>2.18E+05</b>	2.24E+04	0.00E+00	<b>2.24E+04</b>	<b>1.18E+07</b>	<b>1.18E+07</b>
Fossil Fuel Consumption	MJ	2.46E+06	7.43E+04	<b>2.54E+06</b>	1.10E+05	2.68E+05	<b>3.68E+05</b>	8.96E+04	3.03E+03	6.24E+06	<b>6.34E+06</b>	1.77E+05	3.45E+04	<b>2.11E+05</b>	4.49E+04	0.00E+00	<b>4.49E+04</b>	<b>9.45E+06</b>	<b>9.50E+06</b>

### 6.4.3 Comparative Results of Concrete Building and Steel Building

This section briefly describes the eight environmental measures used to summarize the environmental assessment results provided by the Impact Estimator.

#### 6.4.3.1 Acidification Potential (AP)

Acidification is impact effecting human health when high concentrations of NO<sub>x</sub> and SO<sub>2</sub> are attained. The AP of an air or water emission is calculated on the basis of its H<sup>+</sup> equivalence effect on a mass basis. Calculated values of AP for both type of buildings are shown in Table 6.5. The comparison is shown graphically in Figure 6.1.

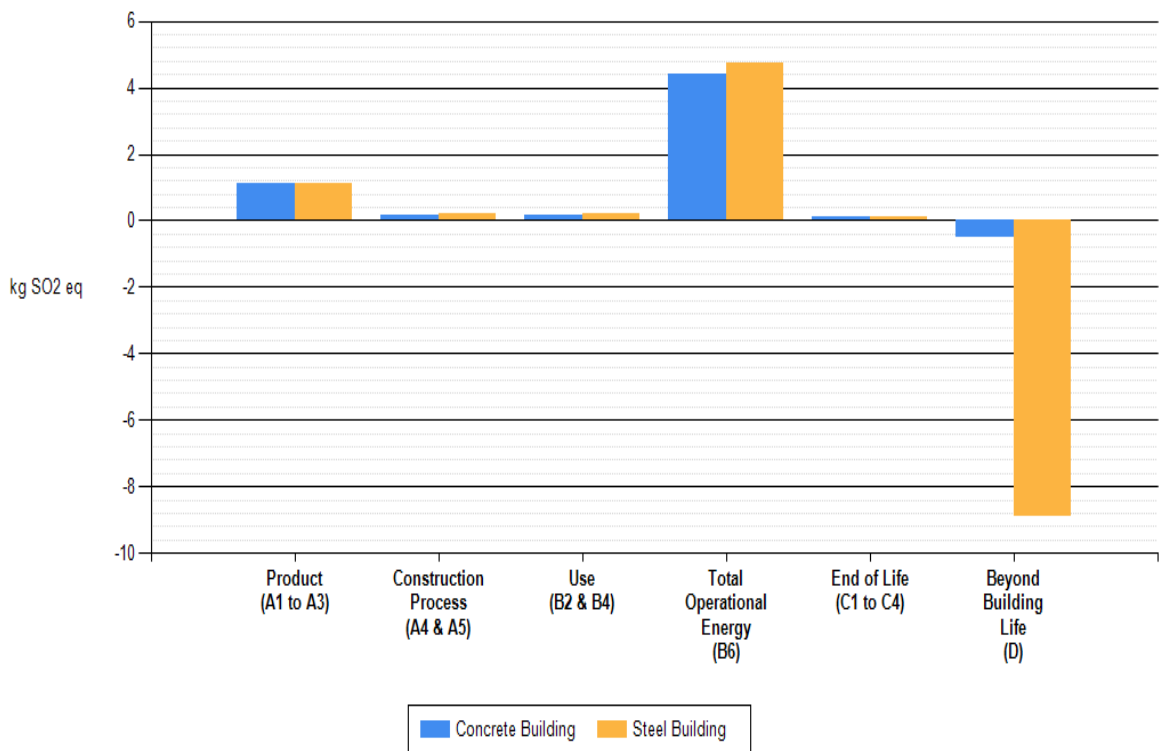


Figure 6.1: Comparison Graph of Acidification Potential by Life Cycle Stage [Per m<sup>2</sup>]

Table 6.5: Results of Acidification Potential by Life Cycle Stage [Per m<sup>2</sup>]

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Total
Concrete Building	kg SO <sub>2</sub> eq	1.11E+00	1.62E-01	1.80E-01	4.40E+00	1.17E-01	-5.03E-01	5.46E+00
Steel Building	kg SO <sub>2</sub> eq	1.14E+00	2.00E-01	1.95E-01	4.75E+00	1.25E-01	-8.91E+00	-2.50E+00
<b>Total</b>	<b>kg SO<sub>2</sub> eq</b>	<b>2.24E+00</b>	<b>3.62E-01</b>	<b>3.75E-01</b>	<b>9.14E+00</b>	<b>2.42E-01</b>	<b>-9.41E+00</b>	<b>2.95E+00</b>

### 6.4.3.2 Aquatic Eutrophication Potential

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. The calculated result is expressed on an equivalent mass of nitrogen (N) basis. Calculated values of Aquatic Eutrophication Potential for both type of buildings are shown in Table 6.6. The comparison is shown graphically in Figure 6.2.

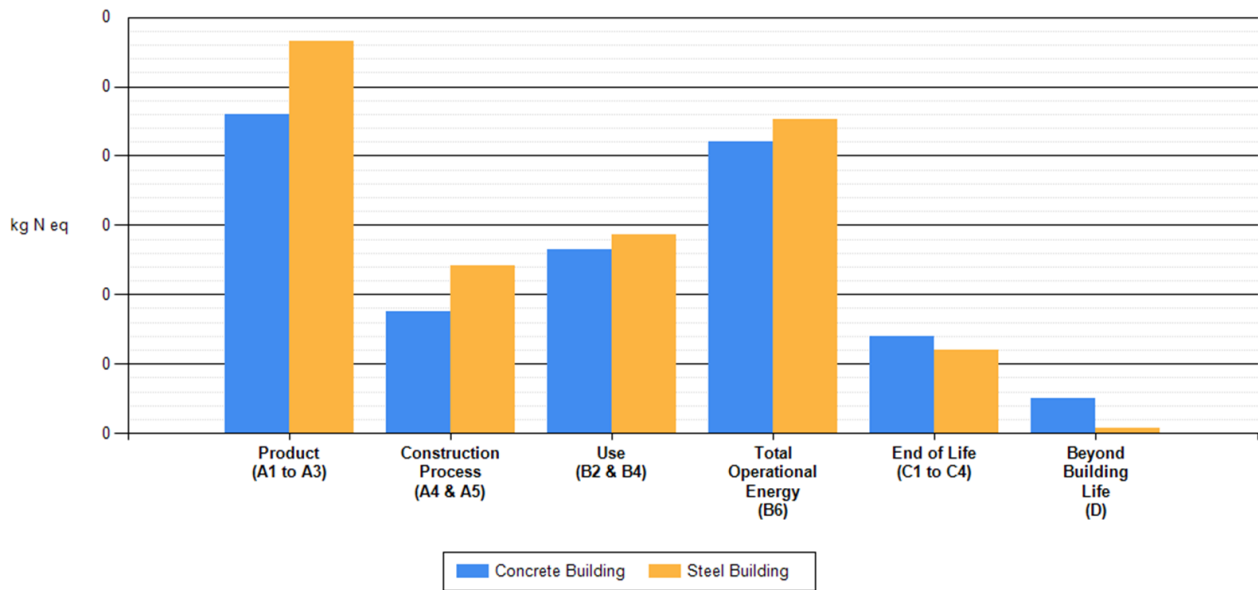


Figure 6.2: Comparison Graph of Eutrophication Potential by Life Cycle Stage [Per m<sup>2</sup>]

Table 6.6: Result of Eutrophication Potential by Life Cycle Stage [Per m<sup>2</sup>]

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Total
Concrete Building	kg N eq	2.30E-02	8.80E-03	1.33E-02	2.10E-02	6.97E-03	2.48E-03	7.55E-02
Steel Building	kg N eq	2.83E-02	1.21E-02	1.43E-02	2.27E-02	6.04E-03	3.83E-04	8.38E-02
<b>Total</b>	<b>kg N eq</b>	<b>5.13E-02</b>	<b>2.09E-02</b>	<b>2.76E-02</b>	<b>4.37E-02</b>	<b>1.30E-02</b>	<b>2.86E-03</b>	<b>1.59E-01</b>

### 6.4.3.3 Global Warming Potential (GWP)

Carbon dioxide is the common reference standard for global warming or greenhouse gas effects. All other greenhouse gases are referred to as having a "CO<sub>2</sub> equivalence effect" which is simply a multiple of the greenhouse potential (heat trapping

capability) of carbon dioxide. This effect has a time horizon due to the atmospheric reactivity or stability of the various contributing gases over time. GWP will be expressed on an equivalency basis relative to CO<sub>2</sub> – in kg or tonnes CO<sub>2</sub> equivalent.

While greenhouse gas emissions are largely a function of energy combustion, some products also emit greenhouse gases during the processing of raw materials. Process emissions often go unaccounted for due to the complexity associated with modelling manufacturing process stages. One example where process CO<sub>2</sub> emissions are significant is in the production of cement (calcination of limestone). Because the Impact Estimator uses data developed by a detailed life cycle modelling approach, all relevant process emissions of greenhouse gases are included in the resultant global warming potential index. Values for GWP are calculated using Athena Impact Estimator for Buildings and are shown in Table 6.7 for both Concrete Building and Steel Building. The comparison is shown graphically for both type of buildings in Figure 6.3.

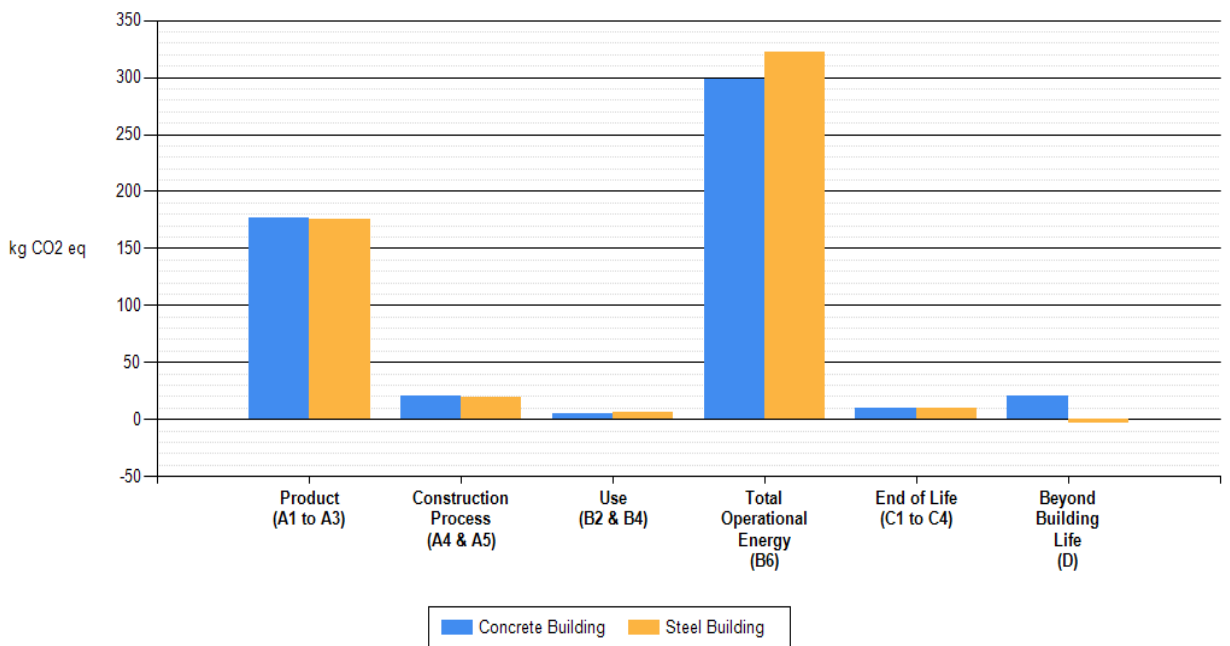


Figure 6.3: Comparison Graph of Global Warming Potential by Life Cycle Stage [Per m<sup>2</sup>]

Table 6.7: Results of Global Warming Potential by Life Cycle Stage [Per m<sup>2</sup>]

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Total
Concrete Building	kg CO <sub>2</sub> eq	1.76E+02	2.00E+01	5.48E+00	2.98E+02	9.82E+00	2.08E+01	5.30E+02
Steel Building	kg CO <sub>2</sub> eq	1.75E+02	1.97E+01	5.92E+00	3.22E+02	1.00E+01	-2.99E+00	5.30E+02
<b>Total</b>	<b>kg CO<sub>2</sub> eq</b>	<b>3.52E+02</b>	<b>3.97E+01</b>	<b>1.14E+01</b>	<b>6.20E+02</b>	<b>1.99E+01</b>	<b>1.78E+01</b>	<b>1.06E+03</b>



### 6.4.3.5 Photochemical Ozone Formation Potential (Smog)

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 (NO<sub>x</sub>). The “smog” indicator is expressed on a mass of equivalent O<sub>3</sub> basis. Values for Smog are calculated using Athena Impact Estimator for Buildings and are shown in Table 6.9. The comparison is shown graphically for both type of buildings in Figure 6.5.

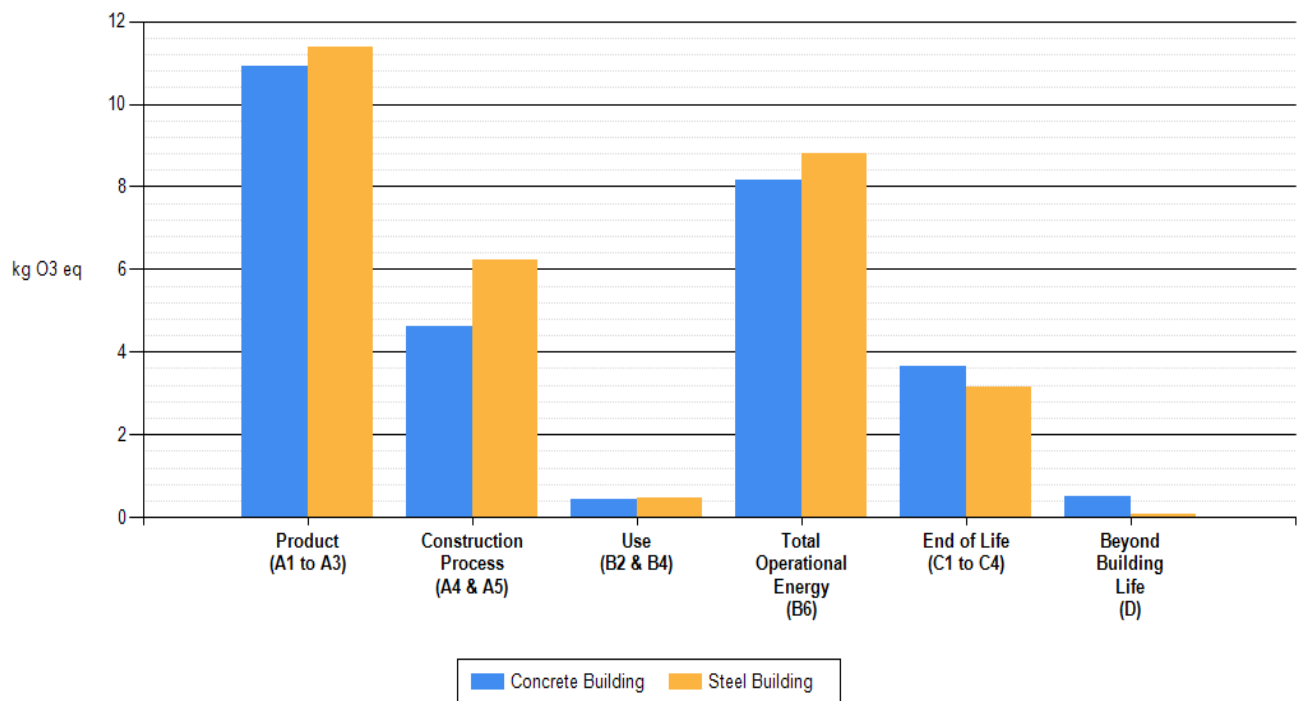


Figure 6.5: Comparison Graph of Smog Potential by Life Cycle Stage [Per m<sup>2</sup>]

Table 6.9: Results of Smog Potential by Life Cycle Stage [Per m<sup>2</sup>]

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Total
Concrete Building	kg O <sub>3</sub> eq	1.09E+01	4.63E+00	4.26E-01	8.17E+00	3.65E+00	4.87E-01	2.83E+01
Steel Building	kg O <sub>3</sub> eq	1.14E+01	6.22E+00	4.61E-01	8.82E+00	3.15E+00	7.67E-02	3.01E+01
<b>Total</b>	<b>kg O<sub>3</sub> eq</b>	<b>2.23E+01</b>	<b>1.09E+01</b>	<b>8.87E-01</b>	<b>1.70E+01</b>	<b>6.80E+00</b>	<b>5.64E-01</b>	<b>5.84E+01</b>

### 6.4.3.6 Total Primary Energy

Total Primary Energy Consumption is reported in mega-joules (MJ) at the bottom of the Energy Consumption absolute value table as well as the Detailed and Condensed Summary Measure tables. Embodied primary energy includes all energy, direct and indirect, used to transform or transport raw materials into products and buildings, including inherent energy contained in raw or feedstock materials that are also used as common energy sources. Values for Total Primary energy are calculated and shown in Table 6.10 for both Concrete Building and Steel Building. The comparison is shown graphically for both type of buildings in Figure 6.6.

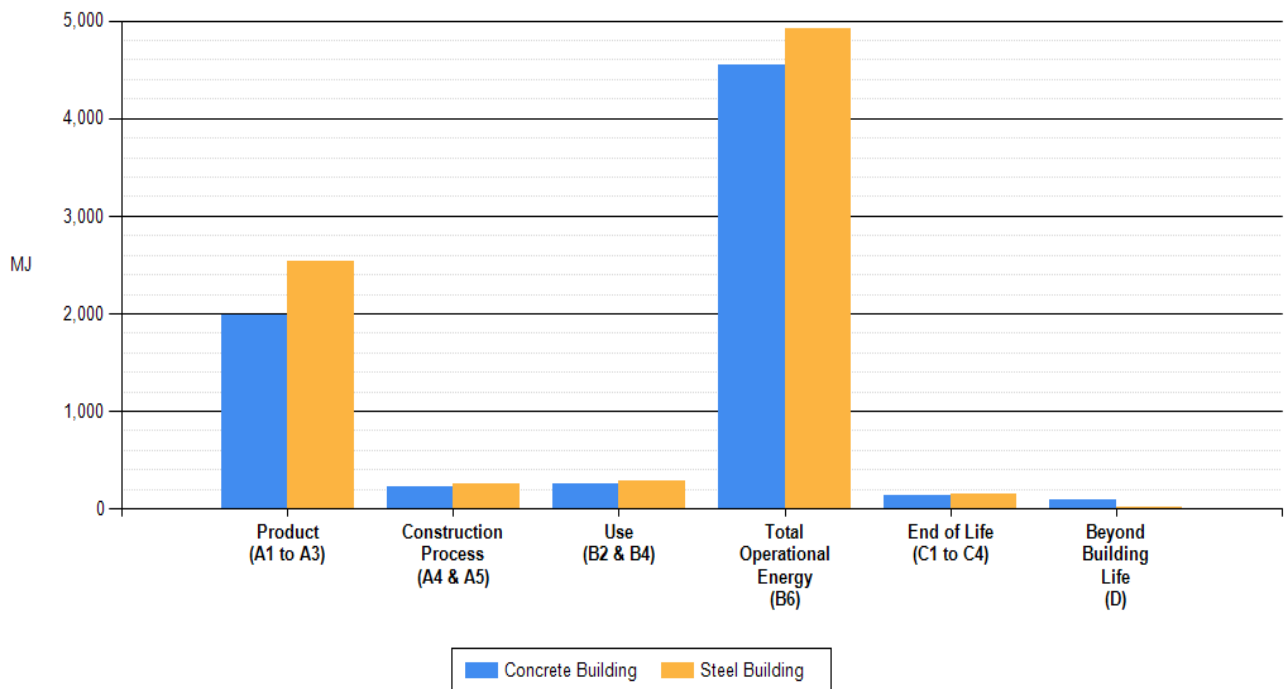


Figure 6.6: Comparison Graph of Total Primary Energy by Life Cycle Stage [Per m²]

Table 6.10: Results of Total Primary Energy by Life Cycle Stage [Per m²]

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Total
Concrete Building	MJ	1.98E+03	2.32E+02	2.61E+02	4.55E+03	1.38E+02	9.65E+01	7.26E+03
Steel Building	MJ	2.53E+03	2.60E+02	2.82E+02	4.91E+03	1.47E+02	1.49E+01	8.15E+03
<b>Total</b>	<b>MJ</b>	<b>4.51E+03</b>	<b>4.92E+02</b>	<b>5.43E+02</b>	<b>9.46E+03</b>	<b>2.85E+02</b>	<b>1.11E+02</b>	<b>1.54E+04</b>

### 6.4.3.7 Non-Renewable Energy

Non-Renewable Energy is a subtotal of Total Primary Energy, by energy type, that includes all fossil fuel energies and nuclear energy. Calculated values of Aquatic Eutrophication Potential for both type of buildings are shown in Table 6.11. The comparison is shown graphically in Figure 6.7.

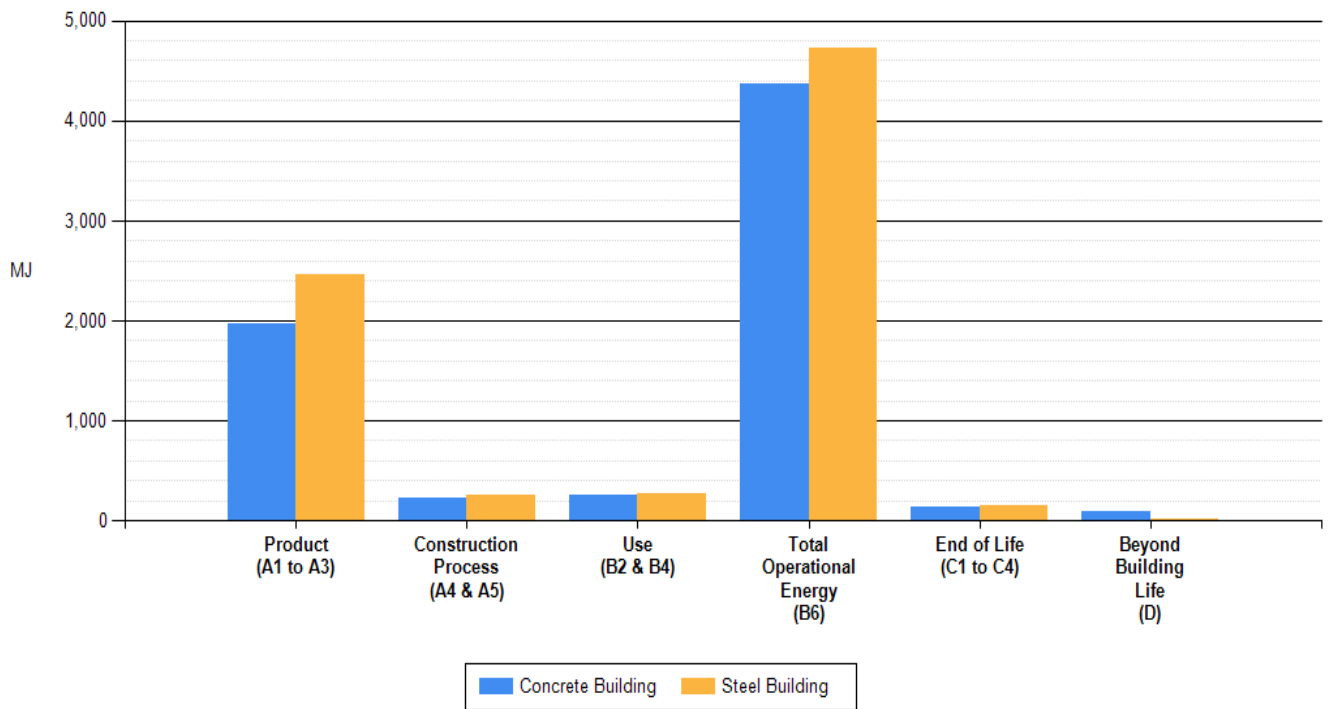


Figure 6.7: Comparison Graph of Non-Renewable Energy by Life Cycle Stage [Per m²]

Table 6.11: Results of Non-Renewable Energy by Life Cycle Stage [Per m²]

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Total
Concrete Building	MJ	1.96E+03	2.31E+02	2.50E+02	4.37E+03	1.38E+02	9.65E+01	7.05E+03
Steel Building	MJ	2.46E+03	2.57E+02	2.70E+02	4.72E+03	1.45E+02	1.49E+01	7.87E+03
<b>Total</b>	<b>MJ</b>	<b>4.42E+03</b>	<b>4.89E+02</b>	<b>5.21E+02</b>	<b>9.09E+03</b>	<b>2.83E+02</b>	<b>1.11E+02</b>	<b>1.49E+04</b>

### 6.4.3.8 Fossil Fuel Consumption

Fossil Fuel Consumption is a subtotal of Total Primary Energy, by energy type, that includes all fossil fuel energies. Values for Fossil Fuel Consumption are calculated using Athena Impact Estimator for Buildings and are shown in Table 6.12. The comparison is shown graphically for both type of buildings in Figure 6.8.

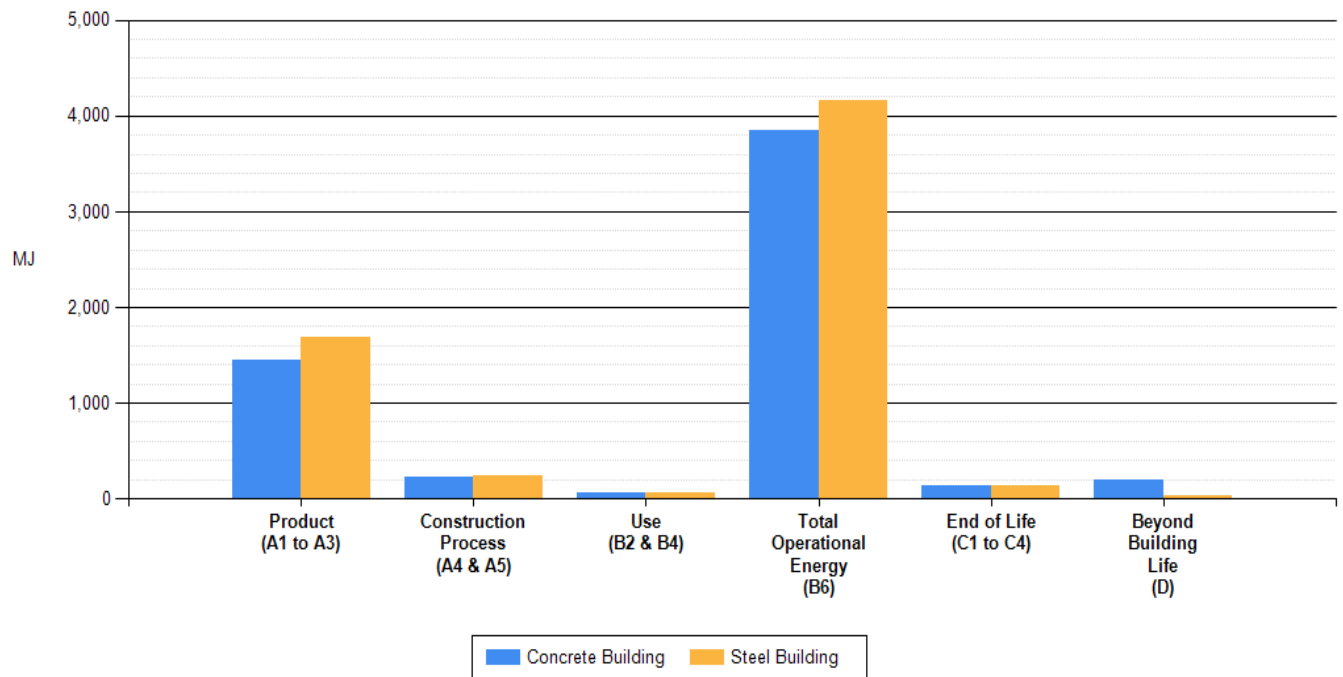


Figure 6.8: Comparison Graph of Fossil Fuel Consumption by Life Cycle Stage [Per m²]

Table 6.12: Results of Fossil Fuel Consumption by Life Cycle Stage [Per m²]

Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Total
Concrete Building	MJ	1.45E+03	2.24E+02	5.72E+01	3.85E+03	1.36E+02	1.94E+02	5.92E+03
Steel Building	MJ	1.69E+03	2.45E+02	6.17E+01	4.16E+03	1.41E+02	2.99E+01	6.33E+03
<b>Total</b>	<b>MJ</b>	<b>3.15E+03</b>	<b>4.70E+02</b>	<b>1.19E+02</b>	<b>8.02E+03</b>	<b>2.76E+02</b>	<b>2.23E+02</b>	<b>1.22E+04</b>

## 6.5 Summary of Results

### 6.5.1 Comparative Result According to Life Cycle Stage [Per m<sup>2</sup>]

Table 6.13: Comparative Report (A to D) by Life Cycle Stage [Per m<sup>2</sup>] of both buildings

Summary Measure	Unit	Concrete Building Total Effects A to D	Steel Building Total Effects A to D
Acidification Potential	kg SO <sub>2</sub> eq	5.46E+00	-2.50E+00
Aquatic Eutrophication Potential	kg N eq	7.55E-02	8.38E-02
Global Warming Potential	kg CO <sub>2</sub> eq	5.30E+02	5.30E+02
Ozone Depletion Potential	kg CFC-11 eq	1.58E-06	9.90E-07
Smog Potential	kg O <sub>3</sub> eq	2.83E+01	3.01E+01
Total Primary Energy	MJ	7.26E+03	8.15E+03
Non-Renewable Energy	MJ	7.05E+03	7.87E+03
Fossil Fuel Consumption	MJ	5.92E+03	6.33E+03

### 6.5.2 Comparative Result According to Green Globes Rating System

Table 6.14: Comparative Report (A to D) by Life Cycle Stage of both buildings

Summary Measure	Unit	Concrete Building Total Effects A to D	Steel Building Total Effects A to D
Global Warming Potential	kg CO <sub>2</sub> eq	8.59E+05	7.95E+05
Acidification Potential	kg SO <sub>2</sub> eq	5.05E+03	4.93E+03
Eutrophication Potential	kg N eq	1.22E+02	1.26E+02
Ozone Depletion Potential	kg CFC-11 eq	2.56E-03	1.48E-03
Smog Potential	kg O <sub>3</sub> eq	4.58E+04	4.52E+04
Fossil Fuel Consumption	MJ	9.59E+06	9.50E+06

### 6.5.3 Green Globes Summary Measure Comparison Report (A to D)

This report can be obtained by selecting one building as a Reference Design and other one as a Proposed Design at a time. Comparative results provides a fair idea about environmental effects of one building with respect to other building. In this thesis following two cases arises for comparison report.

#### 6.5.3.1 Case I

Here Concrete building is considered as Reference Design and Steel Building as Proposed Design. Results obtained are shown in Table 6.15 and shown graphically in Figure 6.9.

Reference Design: Concrete Building

Proposed Design: Steel Building

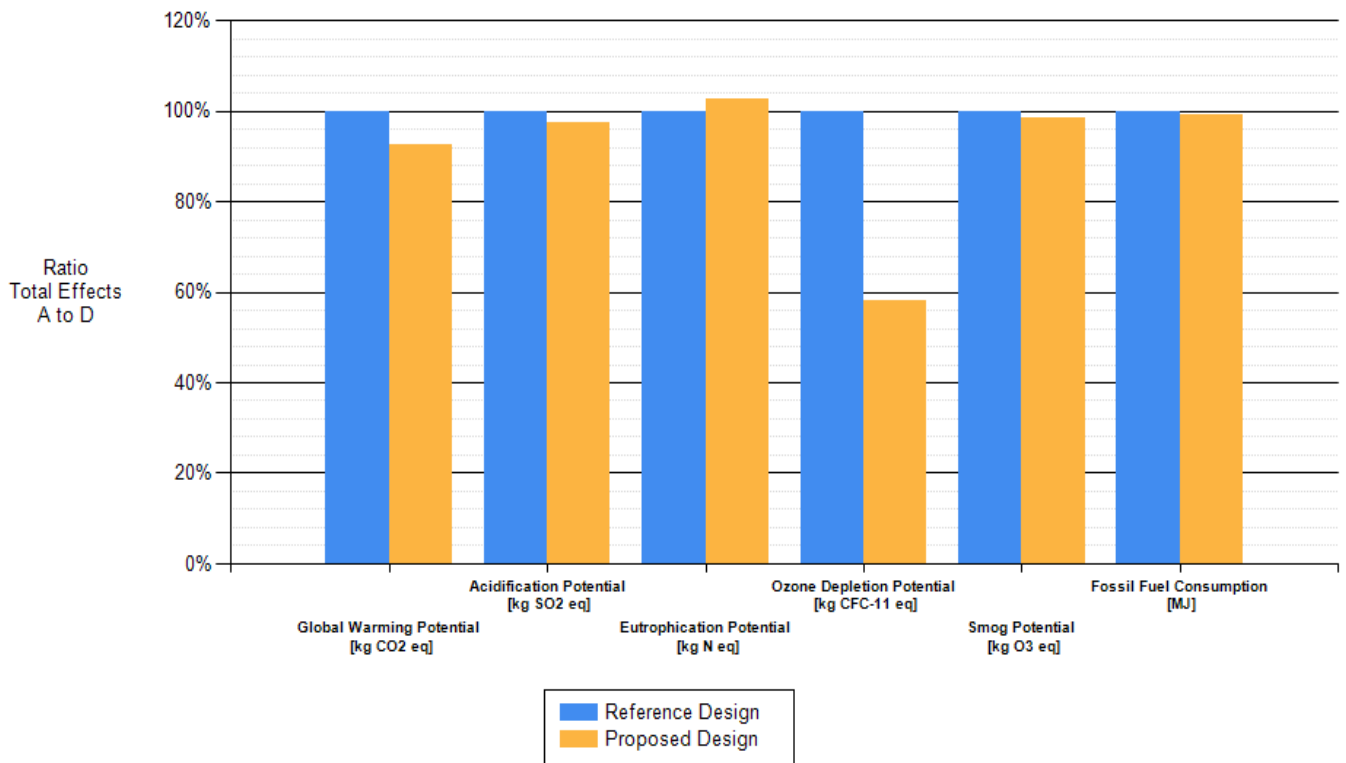


Figure 6.9: Comparison Graph According to Green Globes for Case I

Table 6.15: Results of Green Globes Comparison Report (A to D) for Case I

Summary Measure	Unit	Reference Design Total Effects A to D	Proposed Design Total Effects A to D	% Difference
Global Warming Potential	kg CO2 eq	8.59E+05	7.95E+05	-7.50%
Acidification Potential	kg SO2 eq	5.05E+03	4.93E+03	-2.43%
Eutrophication Potential	kg N eq	1.22E+02	1.26E+02	2.73%
Ozone Depletion Potential	kg CFC-11 eq	2.56E-03	1.48E-03	-42.02%
Smog Potential	kg O3 eq	4.58E+04	4.52E+04	-1.41%
Fossil Fuel Consumption	MJ	9.59E+06	9.50E+06	-0.98%

### 6.5.3.2 Case II

Here Steel building is considered as Reference Design and Concrete Building as Proposed Design. Results obtained are shown in Table 6.16 and shown graphically in Figure 6.10.

Reference Design: Steel Building

Proposed Design: Concrete Building

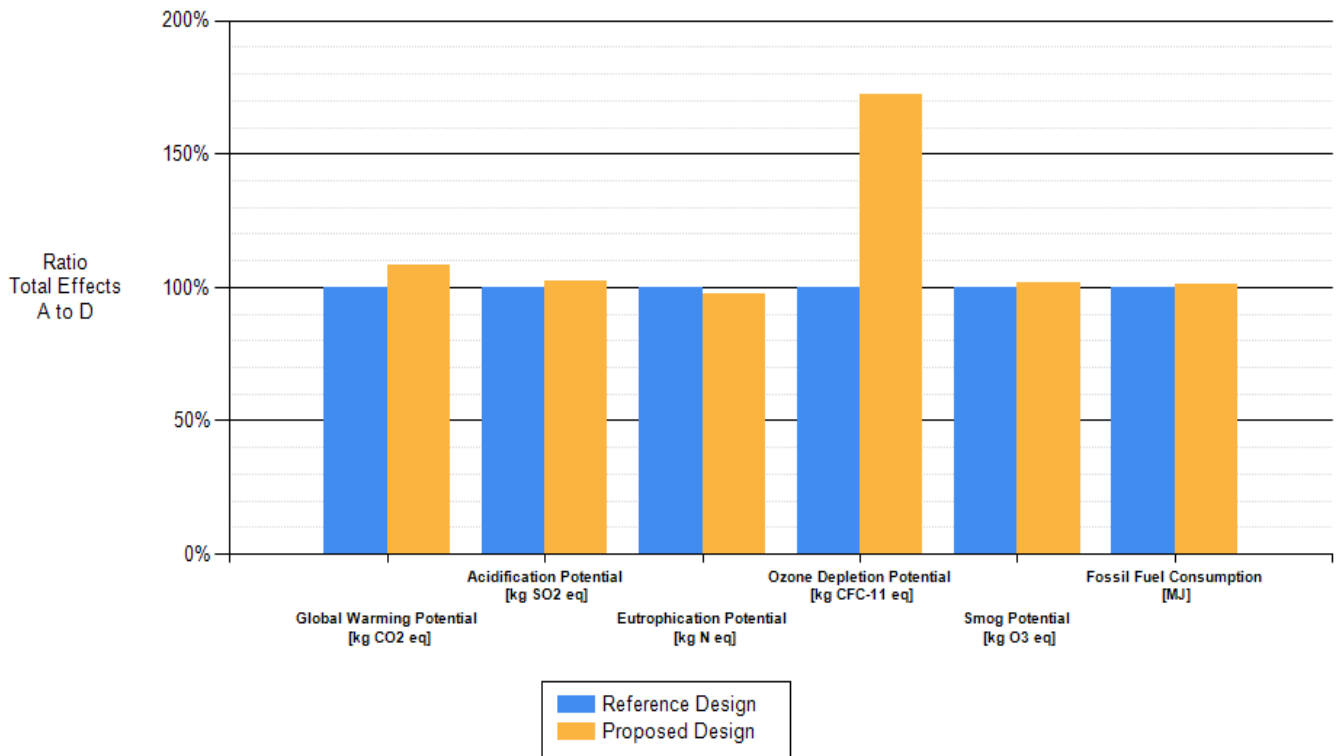


Figure 6.10: Comparison Graph According to Green Globes for Case II

Table 6.16: Results of Green Globes Comparison Report (A to D) for Case II

<b>Summary Measure</b>	<b>Unit</b>	<b>Reference Design Total Effects A to D</b>	<b>Proposed Design Total Effects A to D</b>	<b>% Difference</b>
Global Warming Potential	kg CO2 eq	7.95E+05	8.59E+05	8.11%
Acidification Potential	kg SO2 eq	4.93E+03	5.05E+03	2.49%
Eutrophication Potential	kg N eq	1.26E+02	1.22E+02	-2.65%
Ozone Depletion Potential	kg CFC-11 eq	1.48E-03	2.56E-03	72.46%
Smog Potential	kg O3 eq	4.52E+04	4.58E+04	1.43%
Fossil Fuel Consumption	MJ	9.50E+06	9.59E+06	0.99%

#### 7.1 Summary of Results

The primary objective of this research study and life-cycle assessment was to determine which building material, steel or cast-in-place concrete is 'better' from a sustainability perspective. A summary of the results is given in section 6.5. Conclusion obtained from these results are discussed in next section.

#### 7.2 Conclusion

##### 7.2.1 According to Life Cycle Stage [Per m<sup>2</sup>]

###### 1) Acidification Potential

For the Acidification Potential parameter we can say that output results by Life Cycle Stage [Per m<sup>2</sup>] is in the favour of Steel Building. This is because of reusability of steel after the end of life.

###### 2) Aquatic Eutrophication Potential

For this parameter although there is not much difference in the output values but Concrete building has shown better results than Steel Building. The reason for higher values for steel is excessive nutrient inputs into water and land during early age i.e. during resource harvesting and mining.

###### 3) Global Warming Potential

Contradicting to the Per Square Foot LCA Results suggested by Johnson (Chapter 3), there is no significant difference in result obtained by Athena Impact Estimator. According to Johnson concrete has higher global warming potential than steel. The variation in results is because of type of LCA approach; Johnson considered Cradle-to-Gate approach where as in this thesis Cradle-to-Grave approach is used.

###### 4) Ozone Depletion Potential

This value is higher for Concrete Building than Steel Building because of higher use of raw material, which results into higher emissions of ozone depleting substances to the atmosphere.

#### **5) Smog Potential**

There is not much difference in the results for Smog Potential for both cases. However Steel Building results has higher value because of generation of more volatile organic compounds (VOCs) and nitrogen oxides (NO<sub>x</sub>) during the raw material extraction and manufacturing.

#### **6) Total Primary Energy**

Total energy consumption is higher for Steel Building because of high energy required for manufacturing process and operational requirements.

#### **7) Non-Renewable Energy**

There is no significant difference in results. However values are higher for Steel Building.

#### **8) Fossil Fuel Consumption**

There is no significant difference in the result.

### **7.2.2 According to Green Globes Rating System**

According to the results shown in Table 6.14 it's concluded that Steel Building has better results as compare to Concrete Building. Results are almost similar to the one discussed in section 7.2.1.

### **7.2.3 According to Green Globes Summary Measure Comparison Report (A to D)**

Based on the targeted environmental impacts, the study concludes that steel is 'better' and a more sustainable building material. This study concludes that energy consumption is almost equal and therefore does not effect the determination and conclusion of the LCA comparison.

### 7.3 Future Scope

Without question sustainability is now a decision making tool in the construction and design industry. While the question posed in Chapter 1 of "which material is better?" is answered in this study, the results are fairly close and potentially affected by assumptions made and uncertainty in the data. The conclusion of the study is that steel is 'better', but that conclusion is based on previously mentioned environmental impacts. This definitive conclusion can also be made because in the case of this study steel either has less or equivalent impact of concrete in all impact areas.

Ancillary to defining a 'better' material is the fact that even the 'better' material has a significant impact on the environment. For instance, what is an acceptable threshold of CO<sub>2</sub> emissions? Is choosing steel over concrete going to solve the challenge of global warming? While, this study, and future life cycle assessments may answer the first question of "which is better?" the more important question to answer is "how does industry make both building methods and associate material better?" Again, in the case of steel and concrete-frame construction defined in this study, the 'winner' is steel, but only by a slight margin. Decision makers have to avoid the pitfall of assigning a 'winner' and forgetting the big picture - that both materials, even in only the pre-use phase of a single building - have a significant impact on the global environment.

Apart from above mentioned scope the most important one is that there is a major lack of research in India related to LCA specially related to construction industry. For any LCA study we are dependent on database developed in other part of world such as in European and North American countries. Policies should be developed for to conduct more research for sustainable development with locally available database.

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**Appendix-A**

**Details of system boundaries**

Information Module	Supports?	Processes Included
A1 Raw material supply	Y	Primary resource harvesting and mining
A2 Transport	Y	All transportation of materials up to manufacturing plant gate
A3 Manufacturing	Y	Manufacture of raw materials into products
A4 Transport	Y	Transportation of materials from manufacturing plant to site, and construction equipment to site
A5 Construction-installation process	Y	Construction equipment energy use, and A1-A4, C1, C2, C4 IM effects of construction waste
B1 Installed product in use	N	n/a
B2 Maintenance	Partial	Painted surfaces are maintained (i.e. repainted), but no other maintenance aspects are included
B3 Repair	N	n/a
B4 Replacement	Y	Modules A1-A5 effects of replacement materials, and C1, C2, C4 IM effects of replaced materials
B5 Refurbishment	N	n/a
B6 Operational energy use	Y	Energy primary extraction, production, delivery, and use
B7 Operational water use	N	n/a
C1 De-construction demolition	Y	Demolition equipment energy use
C2 Transport	Y	Transportation of materials from site to landfill
C3 Waste Processing	N	n/a
C4 Disposal	Y	Disposal facility equipment energy use and landfill site effects
D Benefits and loads beyond the system boundary (Beyond Building Life)	Partial	Steel recycling and carbon sequestration of wood products

## Appendix C1

### Bill of Materials Concrete Building

Material	Unit	Total Quantity	Columns & Beams	Floors	Foundations	Roofs	Walls	Mass Value	Mass Unit
8" Concrete Block	Blocks	10576.9156	0	0	0	0	10576.916	200.9614	Tonnes
Aluminum	Tonnes	0.4112	0	0	0	0	0.4112	0.4112	Tonnes
Aluminum Clad Wood Window Frame	kg	1098.9969	0	0	0	0	1098.9969	1.099	Tonnes
Concrete 20 MPa (flyash av)	m3	90.2007	0	0	90.2007	0	0	209.7167	Tonnes
Concrete 30 MPa (flyash av)	m3	389.3863	70.6716	211.0522	0	107.6625	0	905.3231	Tonnes
Double Glazed Hard Coated Air Glazing Panel	m2	186.3118	0	0	0	0	186.3118	3.017	Tonnes
Glazing Panel	Tonnes	0.8112	0	0	0	0	0.8112	0.8112	Tonnes
Mortar	m3	33.7853	0	0	0	0	33.7853	43.2452	Tonnes
Nails	Tonnes	0.0313	0	0	0	0	0.0313	0.0313	Tonnes
Rebar, Rod, Light Sections	Tonnes	58.792	36.3115	11.8777	0.2664	5.6483	4.6881	58.792	Tonnes
Welded Wire Mesh / Ladder Wire	Tonnes	0.488	0	0	0.488	0	0	0.488	Tonnes

## Appendix-C2

### Structural Detailing of Concrete Building

#### 1- Details of Foundations

Sr. No.	Assembly	Length	Width	Thickness	Rebar	Concrete
		(m)	(m)	(mm)		(Mpa)
1	Footing to Columns	32	2	500	#20 M	20
2	Slab for Main Area	22.5	24	100	-	20

#### 2- Details of Columns

Sr. No.	Assembly	No. of Columns	Column Height	Bay Size	Supported Span	Supported Area	Live Load	Supported Element	Column Type
			(m)	(m)	(m)	(m <sup>2</sup> )	(kPa)		
1	Ground Floor Column	20	3.5	7.5	6	540	3.6	Floor	Concrete
2	First Floor Column	20	3.6	7.5	6	540	3.6	Floor	Concrete
3	Second Floor Column	20	3.6	7.5	6	540	3.6	Floor	Concrete

#### 3- Details of Floor

Sr. No.	Assembly	Floor Width	Span	Concrete	Live Load	Floor Area
		(m)	(m)	Mpa	kPa	(m <sup>2</sup> )
1	First Floor Slab	90	6	30	3.6	540
2	Ground Floor Slab	90	6	30	3.6	540

### 3- Details of Walls

Sr. No.	Assembly	Length	Height	Used components	Rebar	No. of Windows	Total Window Area	No. of Doors
		(m)	(m)				(m <sup>2</sup> )	(32"x7")
1	Ground Floor Exterior Wall	90	3.5	Concrete Blocks	#10M	10	25	4
2	First Floor Exterior Wall	90	3.5	Concrete Blocks	#10M	15	37.5	2
3	Second Floor Exterior Wall	90	3.5	Concrete Blocks	#10M	15	37.5	2

### 4- Details of Roof

Sr. No.	Assembly	Roof Width	Span	Concrete	Live Load	Roof Area
		(m)	(m)	Mpa	kPa	(m <sup>2</sup> )
1	Second Floor Roof	90	6	30	2.4	540

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### Appendix C3

### Absolute Values - Energy – Total and primary energy consumed for Concrete Building

		PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS	
Energy Source	Unit	Manufacturing	Transport	Total	Construction- Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
Hydro	MJ	1.84E+04	5.77E+01	<b>1.85E+04</b>	5.35E+02	8.75E+01	<b>6.23E+02</b>	8.90E+03	1.49E+00	1.70E+05	<b>1.79E+05</b>	5.86E+02	3.50E+01	<b>6.21E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.98E+05</b>	<b>1.98E+05</b>
Non-Hydro Renewable	MJ	7.33E+03	0.00E+00	<b>7.33E+03</b>	3.54E+02	0.00E+00	<b>3.54E+02</b>	9.18E+02	0.00E+00	1.21E+05	<b>1.22E+05</b>	3.77E+02	0.00E+00	<b>3.77E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.30E+05</b>	<b>1.30E+05</b>
Coal	MJ	9.88E+05	8.42E+02	<b>9.89E+05</b>	3.05E+04	1.28E+03	<b>3.18E+04</b>	2.42E+04	2.17E+01	2.52E+06	<b>2.54E+06</b>	8.67E+03	5.10E+02	<b>9.18E+03</b>	3.95E+05	0.00E+00	<b>3.95E+05</b>	<b>3.57E+06</b>	<b>3.96E+06</b>
Diesel	MJ	2.99E+04	9.72E+04	<b>1.27E+05</b>	1.15E+05	1.48E+05	<b>2.63E+05</b>	4.33E+03	2.73E+03	1.33E+06	<b>1.33E+06</b>	1.30E+05	5.77E+04	<b>1.87E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.91E+06</b>	<b>1.91E+06</b>
Gasoline	MJ	2.31E-01	0.00E+00	<b>2.31E-01</b>	1.35E+01	0.00E+00	<b>1.35E+01</b>	3.65E-01	0.00E+00	0.00E+00	<b>3.65E-01</b>	1.34E+03	0.00E+00	<b>1.34E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.35E+03</b>	<b>1.35E+03</b>
Heavy Fuel Oil	MJ	5.77E+05	9.98E+03	<b>5.87E+05</b>	2.90E+04	8.69E+03	<b>3.77E+04</b>	2.02E+03	1.47E+02	3.49E+04	<b>3.71E+04</b>	2.87E+03	3.38E+03	<b>6.24E+03</b>	-1.45E+04	0.00E+00	<b>-1.45E+04</b>	<b>6.68E+05</b>	<b>6.54E+05</b>
LPG	MJ	1.15E+03	1.26E+02	<b>1.28E+03</b>	8.17E+01	1.91E+02	<b>2.73E+02</b>	4.68E+01	3.25E+00	4.40E+03	<b>4.45E+03</b>	1.38E+02	7.63E+01	<b>2.14E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.21E+03</b>	<b>6.21E+03</b>
Natural Gas	MJ	6.48E+05	5.14E+03	<b>6.53E+05</b>	2.29E+04	7.80E+03	<b>3.07E+04</b>	5.90E+04	1.33E+02	2.36E+06	<b>2.42E+06</b>	1.24E+04	3.12E+03	<b>1.55E+04</b>	-6.69E+04	0.00E+00	<b>-6.69E+04</b>	<b>3.12E+06</b>	<b>3.05E+06</b>
Nuclear	MJ	8.21E+05	2.13E+02	<b>8.22E+05</b>	1.11E+04	3.22E+02	<b>1.14E+04</b>	3.13E+05	5.49E+00	8.38E+05	<b>1.15E+06</b>	2.82E+03	1.29E+02	<b>2.95E+03</b>	-1.57E+05	0.00E+00	<b>-1.57E+05</b>	<b>1.99E+06</b>	<b>1.83E+06</b>
Wood	MJ	7.47E+03	0.00E+00	<b>7.47E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.47E+03	0.00E+00	0.00E+00	<b>7.47E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.49E+04</b>	<b>1.49E+04</b>
Total Primary Energy Consumption	MJ	3.10E+06	1.14E+05	<b>3.21E+06</b>	2.09E+05	1.67E+05	<b>3.76E+05</b>	4.20E+05	3.04E+03	7.37E+06	<b>7.79E+06</b>	1.59E+05	6.50E+04	<b>2.24E+05</b>	1.56E+05	0.00E+00	<b>1.56E+05</b>	<b>1.16E+07</b>	<b>1.18E+07</b>

## Appendix C4

### Absolute Values - Air Emissions for Concrete Building

Emission	Unit	PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS	
		Manufacturing	Transport	Total	Construction-Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
1,4-Butanediol	g	8.89E-08	0.00E+00	8.89E-08	0.00E+00	0.00E+00	0.00E+00	8.89E-08	0.00E+00	0.00E+00	8.89E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-07	1.78E-07
1-Butanol	g	1.03E-08	0.00E+00	1.03E-08	0.00E+00	0.00E+00	0.00E+00	1.03E-08	0.00E+00	0.00E+00	1.03E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.07E-08	2.07E-08
1-Pentanol	g	2.85E-07	0.00E+00	2.85E-07	0.00E+00	0.00E+00	0.00E+00	2.85E-07	0.00E+00	0.00E+00	2.85E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.70E-07	5.70E-07
1-Pentene	g	2.15E-07	0.00E+00	2.15E-07	0.00E+00	0.00E+00	0.00E+00	2.15E-07	0.00E+00	0.00E+00	2.15E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.31E-07	4.31E-07
1-Propanol	g	2.13E-06	0.00E+00	2.13E-06	0.00E+00	0.00E+00	0.00E+00	2.13E-06	0.00E+00	0.00E+00	2.13E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.27E-06	4.27E-06
2-Butene, 2-methyl-	g	4.78E-11	0.00E+00	4.78E-11	0.00E+00	0.00E+00	0.00E+00	4.78E-11	0.00E+00	0.00E+00	4.78E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.56E-11	9.56E-11
2-Chloroacetophenone	g	7.84E-02	0.00E+00	7.84E-02	4.16E-03	0.00E+00	4.16E-03	2.68E-04	0.00E+00	5.47E-07	2.68E-04	3.15E-09	0.00E+00	3.15E-09	0.00E+00	0.00E+00	0.00E+00	8.28E-02	8.28E-02
2-Methyl-1-propanol	g	4.99E-07	0.00E+00	4.99E-07	0.00E+00	0.00E+00	0.00E+00	4.99E-07	0.00E+00	0.00E+00	4.99E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.99E-07	9.99E-07
2-Propanol	g	5.34E-04	0.00E+00	5.34E-04	0.00E+00	0.00E+00	0.00E+00	5.34E-04	0.00E+00	0.00E+00	5.34E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E-03	1.07E-03
5-methyl Chrysene	g	3.21E-04	0.00E+00	3.21E-04	1.66E-05	0.00E+00	1.66E-05	1.10E-05	0.00E+00	1.15E-03	1.16E-03	3.60E-06	0.00E+00	3.60E-06	0.00E+00	0.00E+00	0.00E+00	1.51E-03	1.51E-03
Acenaphthene	g	7.44E-03	0.00E+00	7.44E-03	3.85E-04	0.00E+00	3.85E-04	2.55E-04	0.00E+00	2.67E-02	2.70E-02	8.36E-05	0.00E+00	8.36E-05	0.00E+00	0.00E+00	0.00E+00	3.49E-02	3.49E-02
Acenaphthylene	g	3.65E-03	0.00E+00	3.65E-03	1.89E-04	0.00E+00	1.89E-04	1.25E-04	0.00E+00	1.31E-02	1.32E-02	4.10E-05	0.00E+00	4.10E-05	0.00E+00	0.00E+00	0.00E+00	1.71E-02	1.71E-02
Acetaldehyde	g	6.89E+00	0.00E+00	6.89E+00	8.13E+00	0.00E+00	8.13E+00	1.22E-01	0.00E+00	4.45E-05	1.22E-01	4.03E+01	0.00E+00	4.03E+01	0.00E+00	0.00E+00	0.00E+00	5.55E+01	5.55E+01
Acetic acid	g	1.83E+01	0.00E+00	1.83E+01	0.00E+00	0.00E+00	0.00E+00	1.83E+01	0.00E+00	0.00E+00	1.83E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.66E+01	3.66E+01
Acetone	g	5.11E-03	0.00E+00	5.11E-03	0.00E+00	0.00E+00	0.00E+00	5.11E-03	0.00E+00	0.00E+00	5.11E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-02	1.02E-02
Acetophenone	g	1.68E-01	0.00E+00	1.68E-01	8.91E-03	0.00E+00	8.91E-03	5.73E-04	0.00E+00	1.17E-06	5.75E-04	6.75E-09	0.00E+00	6.75E-09	0.00E+00	0.00E+00	0.00E+00	1.77E-01	1.77E-01
Acrolein	g	1.56E+01	0.00E+00	1.56E+01	1.07E+00	0.00E+00	1.07E+00	1.30E+01	0.00E+00	1.52E+01	2.82E+01	4.91E+00	0.00E+00	4.91E+00	0.00E+00	0.00E+00	0.00E+00	4.97E+01	4.97E+01
Acrylic acid	g	1.38E-06	0.00E+00	1.38E-06	0.00E+00	0.00E+00	0.00E+00	1.38E-06	0.00E+00	0.00E+00	1.38E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-06	2.77E-06
Aldehydes	g	4.53E+00	0.00E+00	4.53E+00	2.38E-03	0.00E+00	2.38E-03	4.48E+00	0.00E+00	7.80E-01	5.26E+00	2.44E-03	0.00E+00	2.44E-03	0.00E+00	0.00E+00	0.00E+00	9.79E+00	9.79E+00
Ammonia	g	3.99E+02	1.58E+02	5.57E+02	1.80E+01	2.41E+02	2.59E+02	2.64E+02	4.06E+00	6.75E+02	9.44E+02	6.12E+01	9.64E+01	1.58E+02	0.00E+00	0.00E+00	0.00E+00	1.92E+03	1.92E+03
Ammonium chloride	g	9.07E+01	0.00E+00	9.07E+01	6.47E-01	0.00E+00	6.47E-01	7.90E+01	0.00E+00	2.12E+02	2.91E+02	6.63E-01	0.00E+00	6.63E-01	0.00E+00	0.00E+00	0.00E+00	3.83E+02	3.83E+02
Anthracene	g	3.07E-03	0.00E+00	3.07E-03	1.59E-04	0.00E+00	1.59E-04	1.05E-04	0.00E+00	1.10E-02	1.11E-02	3.44E-05	0.00E+00	3.44E-05	0.00E+00	0.00E+00	0.00E+00	1.44E-02	1.44E-02
Antimony	g	2.88E-01	0.00E+00	2.88E-01	1.36E-02	0.00E+00	1.36E-02	3.45E-02	0.00E+00	9.44E-01	9.78E-01	2.95E-03	0.00E+00	2.95E-03	0.00E+00	0.00E+00	0.00E+00	1.28E+00	1.28E+00
Arsenic	g	6.03E+00	0.00E+00	6.03E+00	3.05E-01	0.00E+00	3.05E-01	2.92E-01	0.00E+00	2.43E+01	2.45E+01	8.13E-02	0.00E+00	8.13E-02	0.00E+00	0.00E+00	0.00E+00	3.10E+01	3.10E+01
Benzene	g	1.09E+03	0.00E+00	1.09E+03	6.63E+01	0.00E+00	6.63E+01	2.19E+01	0.00E+00	7.02E+01	9.21E+01	4.93E+01	0.00E+00	4.93E+01	0.00E+00	0.00E+00	0.00E+00	1.30E+03	1.30E+03
Benzene, 1,2-dichloro-	g	5.41E-07	0.00E+00	5.41E-07	0.00E+00	0.00E+00	0.00E+00	5.41E-07	0.00E+00	0.00E+00	5.41E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-06	1.08E-06
Benzene, chloro-	g	2.46E-01	0.00E+00	2.46E-01	1.31E-02	0.00E+00	1.31E-02	8.41E-04	0.00E+00	1.72E-06	8.43E-04	9.90E-09	0.00E+00	9.90E-09	0.00E+00	0.00E+00	0.00E+00	2.60E-01	2.60E-01
Benzene, ethyl-	g	1.22E+00	0.00E+00	1.22E+00	5.58E-02	0.00E+00	5.58E-02	1.75E-01	0.00E+00	7.34E-06	1.75E-01	4.23E-08	0.00E+00	4.23E-08	0.00E+00	0.00E+00	0.00E+00	1.45E+00	1.45E+00
Benzo(a)anthracene	g	1.17E-03	0.00E+00	1.17E-03	6.05E-05	0.00E+00	6.05E-05	4.01E-05	0.00E+00	4.20E-03	4.24E-03	1.31E-05	0.00E+00	1.31E-05	0.00E+00	0.00E+00	0.00E+00	5.48E-03	5.48E-03
Benzo(a)pyrene	g	6.02E+00	0.00E+00	6.02E+00	2.87E-05	0.00E+00	2.87E-05	6.02E+00	0.00E+00	1.99E-03	6.02E+00	6.23E-06	0.00E+00	6.23E-06	0.00E+00	0.00E+00	0.00E+00	1.20E+01	1.20E+01
Benzo(b,j,k)fluoranthene	g	1.61E-03	0.00E+00	1.61E-03	8.31E-05	0.00E+00	8.31E-05	5.49E-05	0.00E+00	5.77E-03	5.82E-03	1.80E-05	0.00E+00	1.80E-05	0.00E+00	0.00E+00	0.00E+00	7.53E-03	7.53E-03
Benzo(ghi)perylene	g	3.94E-04	0.00E+00	3.94E-04	2.04E-05	0.00E+00	2.04E-05	1.36E-05	0.00E+00	1.42E-03	1.43E-03	4.42E-06	0.00E+00	4.42E-06	0.00E+00	0.00E+00	0.00E+00	1.85E-03	1.85E-03
Benzyl chloride	g	7.84E+00	0.00E+00	7.84E+00	4.16E-01	0.00E+00	4.16E-01	2.68E-02	0.00E+00	5.47E-05	2.68E-02	3.15E-07	0.00E+00	3.15E-07	0.00E+00	0.00E+00	0.00E+00	8.28E+00	8.28E+00
Beryllium	g	2.83E-01	0.00E+00	2.83E-01	1.44E-02	0.00E+00	1.44E-02	1.51E-02	0.00E+00	2.62E+00	2.64E+00	1.21E-02	0.00E+00	1.21E-02	0.00E+00	0.00E+00	0.00E+00	2.95E+00	2.95E+00
Biphenyl	g	2.48E-02	0.00E+00	2.48E-02	1.28E-03	0.00E+00	1.28E-03	8.49E-04	0.00E+00	8.92E-02	9.00E-02	2.79E-04	0.00E+00	2.79E-04	0.00E+00	0.00E+00	0.00E+00	1.16E-01	1.16E-01
Bromoform	g	4.37E-01	0.00E+00	4.37E-01	2.32E-02	0.00E+00	2.32E-02	1.49E-03	0.00E+00	3.05E-06	1.49E-03	1.75E-08	0.00E+00	1.75E-08	0.00E+00	0.00E+00	0.00E+00	4.61E-01	4.61E-01
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene)	g	1.87E+01	0.00E+00	1.87E+01	0.00E+00	0.00E+00	0.00E+00	1.87E+01	0.00E+00	0.00E+00	1.87E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.74E+01	3.74E+01
Butadiene	g	2.50E-02	0.00E+00	2.50E-02	3.97E-01	0.00E+00	3.97E-01	4.09E-03	0.00E+00	0.00E+00	4.09E-03	2.06E+00	0.00E+00	2.06E+00	0.00E+00	0.00E+00	0.00E+00	2.48E+00	2.48E+00
Butane	g	9.19E+00	0.00E+00	9.19E+00	0.00E+00	0.00E+00	0.00E+00	9.19E+00	0.00E+00	0.00E+00	9.19E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.84E+01	1.84E+01
Butyrolactone	g	8.28E-09	0.00E+00	8.28E-09	0.00E+00	0.00E+00	0.00E+00	8.28E-09	0.00E+00	0.00E+00	8.28E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.66E-08	1.66E-08
Cadmium	g	2.52E+00	0.00E+00	2.52E+00	6.54E-02	0.00E+00	6.54E-02	7.52E-02	0.00E+00	5.37E+00	5.44E+00	2.08E-02	0.00E+00	2.08E-02	1.13E+00	0.00E+00	1.13E+00	8.05E+00	9.18E+00
Carbon dioxide, biogenic	kg	6.46E+02	0.00E+00	6.46E+02	4.29E-04	0.00E+00	4.29E-04	6.85E+02	0.00E+00	0.00E+00	6.85E+02	8.36E-03	0.00E+00	8.36E-03	0.00E+00	0.00E+00	0.00E+00	1.33E+03	1.33E+03
Carbon dioxide, biogenic, landfill	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-9.02E+02	0.00E+00	-9.02E+02
Carbon dioxide, fossil	kg	2.64E+05	8.56E+03	2.73E+05	1.85E+04	1.30E+04	3.15E+04	7.40E+03	2.21E+02	4.42E+05	4.50E+05	1.02E+04	5.18E+03	1.53E+04	3.17E+04	0.00E+00	3.17E+04	7.70E+05	8.01E+05
Carbon dioxide, land transformation	g	4.35E+05	0.00E+00	4.35E+05	1.26E+04	0.00E+00	1.26E+04	2.10E+05	0.00E+00	4.01E+06	4.22E+06	1.25E+04	0.00E+00	1.25E+04	0.00E+00	0.00E+00	0.00E+00	4.68E+06	4.68E+06

Carbon disulfide	g	1.49E+00	0.00E+00	<b>1.49E+00</b>	7.72E-02	0.00E+00	<b>7.72E-02</b>	3.68E-02	0.00E+00	1.02E-05	<b>3.68E-02</b>	5.85E-08	0.00E+00	<b>5.85E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.60E+00</b>	<b>1.60E+00</b>
Carbon monoxide	g	6.22E+04	1.38E+04	<b>7.60E+04</b>	4.40E+04	2.17E+04	<b>6.57E+04</b>	5.24E+03	4.14E+02	6.34E+01	<b>5.72E+03</b>	3.67E-01	8.20E+03	<b>8.20E+03</b>	5.08E+05	0.00E+00	<b>5.08E+05</b>	<b>1.56E+05</b>	<b>6.64E+05</b>
Carbon monoxide, fossil	g	1.71E+05	3.06E+04	<b>2.02E+05</b>	2.42E+04	4.66E+04	<b>7.08E+04</b>	6.14E+03	8.51E+02	5.13E+05	<b>5.20E+05</b>	8.35E+04	1.81E+04	<b>1.02E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.95E+05</b>	<b>8.95E+05</b>
Chloride	g	1.64E+00	0.00E+00	<b>1.64E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.64E+00	0.00E+00	0.00E+00	<b>1.64E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.28E+00</b>	<b>3.28E+00</b>
Chlorine	g	2.70E+00	0.00E+00	<b>2.70E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.70E+00	0.00E+00	0.00E+00	<b>2.70E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.40E+00</b>	<b>5.40E+00</b>
Chloroform	g	6.61E-01	0.00E+00	<b>6.61E-01</b>	3.51E-02	0.00E+00	<b>3.51E-02</b>	2.27E-03	0.00E+00	4.61E-06	<b>2.27E-03</b>	2.65E-08	0.00E+00	<b>2.65E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.98E-01</b>	<b>6.98E-01</b>
Chromium	g	1.16E+01	0.00E+00	<b>1.16E+01</b>	3.58E-01	0.00E+00	<b>3.58E-01</b>	2.51E-01	0.00E+00	1.68E+01	<b>1.70E+01</b>	5.67E-02	0.00E+00	<b>5.67E-02</b>	-3.29E+00	0.00E+00	<b>-3.29E+00</b>	<b>2.91E+01</b>	<b>2.58E+01</b>
Chromium VI	g	1.15E+00	0.00E+00	<b>1.15E+00</b>	5.97E-02	0.00E+00	<b>5.97E-02</b>	3.96E-02	0.00E+00	4.14E+00	<b>4.18E+00</b>	1.29E-02	0.00E+00	<b>1.29E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.41E+00</b>	<b>5.41E+00</b>
Chrysene	g	1.46E-03	0.00E+00	<b>1.46E-03</b>	7.56E-05	0.00E+00	<b>7.56E-05</b>	5.03E-05	0.00E+00	5.24E-03	<b>5.29E-03</b>	1.64E-05	0.00E+00	<b>1.64E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.85E-03</b>	<b>6.85E-03</b>
Cobalt	g	6.00E+00	0.00E+00	<b>6.00E+00</b>	3.01E-01	0.00E+00	<b>3.01E-01</b>	1.28E-01	0.00E+00	7.91E+00	<b>8.04E+00</b>	2.59E-02	0.00E+00	<b>2.59E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.44E+01</b>	<b>1.44E+01</b>
Copper	g	9.38E-02	0.00E+00	<b>9.38E-02</b>	1.30E-03	0.00E+00	<b>1.30E-03</b>	7.26E-02	0.00E+00	3.00E+00	<b>3.07E+00</b>	1.72E-02	0.00E+00	<b>1.72E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.18E+00</b>	<b>3.18E+00</b>
Cumene	g	4.67E+00	0.00E+00	<b>4.67E+00</b>	3.15E-03	0.00E+00	<b>3.15E-03</b>	4.62E+00	0.00E+00	4.14E-07	<b>4.62E+00</b>	2.38E-09	0.00E+00	<b>2.38E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>9.29E+00</b>	<b>9.29E+00</b>
Cyanide	g	2.80E+01	0.00E+00	<b>2.80E+01</b>	1.49E+00	0.00E+00	<b>1.49E+00</b>	1.27E-01	0.00E+00	1.95E-04	<b>1.27E-01</b>	1.62E-06	0.00E+00	<b>1.62E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.96E+01</b>	<b>2.96E+01</b>
Dimethyl ether	g	3.23E-02	0.00E+00	<b>3.23E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.23E-02	0.00E+00	0.00E+00	<b>3.23E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.46E-02</b>	<b>6.46E-02</b>
Dinitrogen monoxide	g	8.47E+03	8.13E-01	<b>8.48E+03</b>	4.49E+02	4.19E-02	<b>4.49E+02</b>	4.72E+01	3.07E-02	2.10E+03	<b>2.15E+03</b>	6.81E+00	5.86E-03	<b>6.82E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.11E+04</b>	<b>1.11E+04</b>
Dioxins, unspecified	g	4.43E-03	0.00E+00	<b>4.43E-03</b>	5.05E-05	0.00E+00	<b>5.05E-05</b>	1.29E-06	0.00E+00	0.00E+00	<b>1.29E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-2.39E-04	0.00E+00	<b>-2.39E-04</b>	<b>4.48E-03</b>	<b>4.24E-03</b>
Ethane	g	3.72E+01	0.00E+00	<b>3.72E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.72E+01	0.00E+00	0.00E+00	<b>3.72E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.44E+01</b>	<b>7.44E+01</b>
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	g	2.93E-02	0.00E+00	<b>2.93E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.93E-02	0.00E+00	0.00E+00	<b>2.93E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.86E-02</b>	<b>5.86E-02</b>
Ethane, 1,1,1-trichloro-, HCFC-140	g	2.25E-01	2.21E-04	<b>2.25E-01</b>	1.20E-02	3.39E-04	<b>1.23E-02</b>	7.86E-04	6.16E-06	2.84E-03	<b>3.63E-03</b>	2.82E-04	1.32E-04	<b>4.14E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.41E-01</b>	<b>2.41E-01</b>
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	g	6.56E-08	0.00E+00	<b>6.56E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.56E-08	0.00E+00	0.00E+00	<b>6.56E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.31E-07</b>	<b>1.31E-07</b>
Ethane, 1,1-difluoro-, HFC-152a	g	8.04E-07	0.00E+00	<b>8.04E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.04E-07	0.00E+00	0.00E+00	<b>8.04E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.61E-06</b>	<b>1.61E-06</b>
Ethane, 1,2-dibromo-	g	1.34E-02	0.00E+00	<b>1.34E-02</b>	7.13E-04	0.00E+00	<b>7.13E-04</b>	4.59E-05	0.00E+00	9.38E-08	<b>4.60E-05</b>	5.40E-10	0.00E+00	<b>5.40E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.42E-02</b>	<b>1.42E-02</b>
Ethane, 1,2-dichloro-	g	4.48E-01	0.00E+00	<b>4.48E-01</b>	2.38E-02	0.00E+00	<b>2.38E-02</b>	2.12E-03	0.00E+00	3.13E-06	<b>2.12E-03</b>	1.80E-08	0.00E+00	<b>1.80E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.74E-01</b>	<b>4.74E-01</b>
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	g	1.15E-04	0.00E+00	<b>1.15E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.15E-04	0.00E+00	0.00E+00	<b>1.15E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.31E-04</b>	<b>2.31E-04</b>
Ethane, chloro-	g	4.70E-01	0.00E+00	<b>4.70E-01</b>	2.50E-02	0.00E+00	<b>2.50E-02</b>	1.61E-03	0.00E+00	3.28E-06	<b>1.61E-03</b>	1.89E-08	0.00E+00	<b>1.89E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.97E-01</b>	<b>4.97E-01</b>
Ethane, hexafluoro-, HFC-116	g	1.24E-04	0.00E+00	<b>1.24E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.24E-04	0.00E+00	0.00E+00	<b>1.24E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.48E-04</b>	<b>2.48E-04</b>
Ethanol	g	6.54E-03	0.00E+00	<b>6.54E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.54E-03	0.00E+00	0.00E+00	<b>6.54E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.31E-02</b>	<b>1.31E-02</b>
Ethene	g	2.86E+00	0.00E+00	<b>2.86E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.86E+00	0.00E+00	0.00E+00	<b>2.86E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.73E+00</b>	<b>5.73E+00</b>
Ethene, chloro-	g	1.21E-04	0.00E+00	<b>1.21E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.21E-04	0.00E+00	0.00E+00	<b>1.21E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.42E-04</b>	<b>2.42E-04</b>
Ethene, tetrachloro-	g	6.82E-01	0.00E+00	<b>6.82E-01</b>	3.52E-02	0.00E+00	<b>3.52E-02</b>	2.22E-02	0.00E+00	2.56E+00	<b>2.58E+00</b>	8.74E-03	0.00E+00	<b>8.74E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.31E+00</b>	<b>3.31E+00</b>
Ethene, trichloro-	g	4.19E-05	0.00E+00	<b>4.19E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.19E-05	0.00E+00	0.00E+00	<b>4.19E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.39E-05</b>	<b>8.39E-05</b>
Ethyl acetate	g	2.48E-03	0.00E+00	<b>2.48E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.48E-03	0.00E+00	0.00E+00	<b>2.48E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.96E-03</b>	<b>4.96E-03</b>
Ethylamine	g	2.57E-07	0.00E+00	<b>2.57E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.57E-07	0.00E+00	0.00E+00	<b>2.57E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.15E-07</b>	<b>5.15E-07</b>
Ethylene oxide	g	1.28E-04	0.00E+00	<b>1.28E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.28E-04	0.00E+00	0.00E+00	<b>1.28E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.55E-04</b>	<b>2.55E-04</b>
Ethyne	g	2.40E+00	0.00E+00	<b>2.40E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.40E+00	0.00E+00	0.00E+00	<b>2.40E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.81E+00</b>	<b>4.81E+00</b>
Fluoranthene	g	1.04E-02	0.00E+00	<b>1.04E-02</b>	5.37E-04	0.00E+00	<b>5.37E-04</b>	3.55E-04	0.00E+00	3.72E-02	<b>3.76E-02</b>	1.16E-04	0.00E+00	<b>1.16E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.86E-02</b>	<b>4.86E-02</b>
Fluorene	g	2.11E-02	0.00E+00	<b>2.11E-02</b>	6.88E-04	0.00E+00	<b>6.88E-04</b>	8.30E-03	0.00E+00	4.77E-02	<b>5.60E-02</b>	1.49E-04	0.00E+00	<b>1.49E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.80E-02</b>	<b>7.80E-02</b>
Fluoride	g	5.01E+02	0.00E+00	<b>5.01E+02</b>	2.65E+01	0.00E+00	<b>2.65E+01</b>	3.48E+00	0.00E+00	4.77E+00	<b>8.25E+00</b>	1.49E-02	0.00E+00	<b>1.49E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.36E+02</b>	<b>5.36E+02</b>
Formaldehyde	g	1.28E+02	0.00E+00	<b>1.28E+02</b>	1.78E+01	0.00E+00	<b>1.78E+01</b>	1.69E+01	0.00E+00	9.65E+01	<b>1.13E+02</b>	6.23E+01	0.00E+00	<b>6.23E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.21E+02</b>	<b>3.21E+02</b>
Formic acid	g	2.04E-03	0.00E+00	<b>2.04E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.04E-03	0.00E+00	0.00E+00	<b>2.04E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.07E-03</b>	<b>4.07E-03</b>
Furan	g	5.95E-04	0.00E+00	<b>5.95E-04</b>	8.08E-07	0.00E+00	<b>8.08E-07</b>	5.81E-04	0.00E+00	2.62E-04	<b>8.43E-04</b>	8.19E-07	0.00E+00	<b>8.19E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.44E-03</b>	<b>1.44E-03</b>
Heptane	g	1.69E+00	0.00E+00	<b>1.69E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.69E+00	0.00E+00	0.00E+00	<b>1.69E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.37E+00</b>	<b>3.37E+00</b>
Hexane	g	4.35E+00	0.00E+00	<b>4.35E+00</b>	3.98E-02	0.00E+00	<b>3.98E-02</b>	3.60E+00	0.00E+00	5.23E-06	<b>3.60E+00</b>	3.01E-08	0.00E+00	<b>3.01E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.99E+00</b>	<b>7.99E+00</b>
Hydrazine, methyl-	g	1.90E+00	0.00E+00	<b>1.90E+00</b>	1.01E-01	0.00E+00	<b>1.01E-01</b>	6.50E-03	0.00E+00</										

Lead	g	5.89E+01	0.00E+00	<b>5.89E+01</b>	1.42E+00	0.00E+00	<b>1.42E+00</b>	5.88E-01	0.00E+00	2.76E+01	<b>2.82E+01</b>	9.85E-02	0.00E+00	<b>9.85E-02</b>	4.08E+01	0.00E+00	<b>4.08E+01</b>	<b>8.86E+01</b>	<b>1.29E+02</b>
m-Xylene	g	8.28E-03	0.00E+00	<b>8.28E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.28E-03	0.00E+00	0.00E+00	<b>8.28E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.66E-02</b>	<b>1.66E-02</b>
Magnesium	g	1.61E+02	0.00E+00	<b>1.61E+02</b>	8.31E+00	0.00E+00	<b>8.31E+00</b>	5.60E+00	0.00E+00	5.77E+02	<b>5.82E+02</b>	1.80E+00	0.00E+00	<b>1.80E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.53E+02</b>	<b>7.53E+02</b>
Manganese	g	1.31E+01	0.00E+00	<b>1.31E+01</b>	4.08E-01	0.00E+00	<b>4.08E-01</b>	5.42E+00	0.00E+00	3.03E+01	<b>3.58E+01</b>	1.03E-01	0.00E+00	<b>1.03E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.94E+01</b>	<b>4.94E+01</b>
Mercaptans, unspecified	g	2.43E+03	0.00E+00	<b>2.43E+03</b>	1.29E+02	0.00E+00	<b>1.29E+02</b>	8.30E+00	0.00E+00	1.70E-02	<b>8.31E+00</b>	9.76E-05	0.00E+00	<b>9.76E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.57E+03</b>	<b>2.57E+03</b>
Mercury	g	2.32E+01	0.00E+00	<b>2.32E+01</b>	8.84E-01	0.00E+00	<b>8.84E-01</b>	1.85E-01	0.00E+00	6.14E+00	<b>6.33E+00</b>	2.32E-02	0.00E+00	<b>2.32E-02</b>	-2.21E-01	0.00E+00	<b>-2.21E-01</b>	<b>3.05E+01</b>	<b>3.03E+01</b>
Metals, unspecified	g	1.37E+02	0.00E+00	<b>1.37E+02</b>	1.52E-05	0.00E+00	<b>1.52E-05</b>	1.37E+02	0.00E+00	0.00E+00	<b>1.37E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.75E+02</b>	<b>2.75E+02</b>
Methacrylic acid, methyl ester	g	2.24E-01	0.00E+00	<b>2.24E-01</b>	1.19E-02	0.00E+00	<b>1.19E-02</b>	7.64E-04	0.00E+00	1.56E-06	<b>7.66E-04</b>	9.00E-09	0.00E+00	<b>9.00E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.37E-01</b>	<b>2.37E-01</b>
Methane	g	3.11E+05	1.20E+02	<b>3.11E+05</b>	9.79E+03	2.60E+02	<b>1.01E+04</b>	3.24E+04	1.05E+01	1.08E+06	<b>1.11E+06</b>	3.40E+03	4.34E+01	<b>3.45E+03</b>	9.64E+04	0.00E+00	<b>9.64E+04</b>	<b>1.44E+06</b>	<b>1.53E+06</b>
Methane, biogenic, landfill	g	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	9.81E+03	0.00E+00	<b>9.81E+03</b>	<b>0.00E+00</b>	<b>9.81E+03</b>
Methane, bromo-, Halon 1001	g	1.79E+00	0.00E+00	<b>1.79E+00</b>	9.51E-02	0.00E+00	<b>9.51E-02</b>	6.12E-03	0.00E+00	1.25E-05	<b>6.13E-03</b>	7.20E-08	0.00E+00	<b>7.20E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.89E+00</b>	<b>1.89E+00</b>
Methane, bromochlorodifluoro-, Halon 1211	g	1.09E-02	0.00E+00	<b>1.09E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.09E-02	0.00E+00	0.00E+00	<b>1.09E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.17E-02</b>	<b>2.17E-02</b>
Methane, bromotrifluoro-, Halon 1301	g	4.40E-03	0.00E+00	<b>4.40E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.40E-03	0.00E+00	0.00E+00	<b>4.40E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.80E-03</b>	<b>8.80E-03</b>
Methane, chlorodifluoro-, HCFC-22	g	3.72E-02	0.00E+00	<b>3.72E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.72E-02	0.00E+00	0.00E+00	<b>3.72E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.44E-02</b>	<b>7.44E-02</b>
Methane, dichloro-, HCC-30	g	8.88E+00	0.00E+00	<b>8.88E+00</b>	4.06E-01	0.00E+00	<b>4.06E-01</b>	1.12E+00	0.00E+00	3.33E+01	<b>3.44E+01</b>	1.47E-01	0.00E+00	<b>1.47E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.38E+01</b>	<b>4.38E+01</b>
Methane, dichlorodifluoro-, CFC-12	g	8.09E-04	2.74E-04	<b>1.08E-03</b>	1.01E-04	4.20E-04	<b>5.21E-04</b>	6.45E-05	7.63E-06	3.51E-03	<b>3.58E-03</b>	3.49E-04	1.63E-04	<b>5.12E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.70E-03</b>	<b>5.70E-03</b>
Methane, dichlorofluoro-, HCFC-21	g	4.39E-10	0.00E+00	<b>4.39E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.39E-10	0.00E+00	0.00E+00	<b>4.39E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.78E-10</b>	<b>8.78E-10</b>
Methane, fossil	g	4.23E+04	8.49E+03	<b>5.08E+04</b>	4.04E+03	1.30E+04	<b>1.71E+04</b>	4.06E+03	2.36E+02	1.93E+05	<b>1.98E+05</b>	1.15E+04	5.06E+03	<b>1.66E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.82E+05</b>	<b>2.82E+05</b>
Methane, monochloro-, R-40	g	5.93E+00	0.00E+00	<b>5.93E+00</b>	3.15E-01	0.00E+00	<b>3.15E-01</b>	2.03E-02	0.00E+00	4.14E-05	<b>2.03E-02</b>	2.38E-07	0.00E+00	<b>2.38E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.27E+00</b>	<b>6.27E+00</b>
Methane, tetrachloro-, CFC-10	g	4.82E-03	2.78E-05	<b>4.85E-03</b>	1.02E-05	4.23E-05	<b>5.24E-05</b>	4.74E-03	7.71E-07	3.51E-04	<b>5.10E-03</b>	3.49E-05	1.64E-05	<b>5.13E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.00E-02</b>	<b>1.00E-02</b>
Methane, tetrafluoro-, CFC-14	g	1.08E-03	0.00E+00	<b>1.08E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.08E-03	0.00E+00	0.00E+00	<b>1.08E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.15E-03</b>	<b>2.15E-03</b>
Methane, trichlorofluoro-, CFC-11	g	7.12E-10	0.00E+00	<b>7.12E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.12E-10	0.00E+00	0.00E+00	<b>7.12E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.42E-09</b>	<b>1.42E-09</b>
Methane, trifluoro-, HFC-23	g	1.40E-07	0.00E+00	<b>1.40E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.40E-07	0.00E+00	0.00E+00	<b>1.40E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.79E-07</b>	<b>2.79E-07</b>
Methanol	g	1.11E+02	0.00E+00	<b>1.11E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.11E+02	0.00E+00	0.00E+00	<b>1.11E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.22E+02</b>	<b>2.22E+02</b>
Methyl acetate	g	8.55E-10	0.00E+00	<b>8.55E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.55E-10	0.00E+00	0.00E+00	<b>8.55E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.71E-09</b>	<b>1.71E-09</b>
Methyl acrylate	g	1.57E-06	0.00E+00	<b>1.57E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.57E-06	0.00E+00	0.00E+00	<b>1.57E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.14E-06</b>	<b>3.14E-06</b>
Methyl amine	g	4.07E-08	0.00E+00	<b>4.07E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.07E-08	0.00E+00	0.00E+00	<b>4.07E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.14E-08</b>	<b>8.14E-08</b>
Methyl ethyl ketone	g	4.37E+00	0.00E+00	<b>4.37E+00</b>	2.32E-01	0.00E+00	<b>2.32E-01</b>	2.18E-02	0.00E+00	3.05E-05	<b>2.18E-02</b>	1.75E-07	0.00E+00	<b>1.75E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.63E+00</b>	<b>4.63E+00</b>
Methyl formate	g	1.44E-07	0.00E+00	<b>1.44E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.44E-07	0.00E+00	0.00E+00	<b>1.44E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.88E-07</b>	<b>2.88E-07</b>
Methyl lactate	g	2.90E-07	0.00E+00	<b>2.90E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.90E-07	0.00E+00	0.00E+00	<b>2.90E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.79E-07</b>	<b>5.79E-07</b>
Methyl methacrylate	g	1.53E-07	0.00E+00	<b>1.53E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.53E-07	0.00E+00	0.00E+00	<b>1.53E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.06E-07</b>	<b>3.06E-07</b>
Monoethanolamine	g	8.10E-05	0.00E+00	<b>8.10E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.10E-05	0.00E+00	0.00E+00	<b>8.10E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.62E-04</b>	<b>1.62E-04</b>
Naphthalene	g	1.44E+00	0.00E+00	<b>1.44E+00</b>	5.64E-02	0.00E+00	<b>5.64E-02</b>	3.42E-01	0.00E+00	1.73E+00	<b>2.08E+00</b>	5.68E-03	0.00E+00	<b>5.68E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.58E+00</b>	<b>3.58E+00</b>
Nickel	g	6.85E+01	0.00E+00	<b>6.85E+01</b>	3.43E+00	0.00E+00	<b>3.43E+00</b>	1.08E+00	0.00E+00	5.44E+01	<b>5.55E+01</b>	1.91E-01	0.00E+00	<b>1.91E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.28E+02</b>	<b>1.28E+02</b>
Nitrate	g	1.21E-03	0.00E+00	<b>1.21E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.21E-03	0.00E+00	0.00E+00	<b>1.21E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.42E-03</b>	<b>2.42E-03</b>
Nitrobenzene	g	1.59E-06	0.00E+00	<b>1.59E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.59E-06	0.00E+00	0.00E+00	<b>1.59E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.18E-06</b>	<b>3.18E-06</b>
Nitrogen dioxide	g	1.11E+02	4.78E+03	<b>4.89E+03</b>	-5.99E+00	7.51E+03	<b>7.51E+03</b>	8.14E+01	1.42E+02	1.51E+01	<b>2.39E+02</b>	8.72E-02	2.86E+03	<b>2.86E+03</b>	3.22E+02	0.00E+00	<b>3.22E+02</b>	<b>1.55E+04</b>	<b>1.58E+04</b>
Nitrogen oxides	g	5.96E+05	1.11E+05	<b>7.07E+05</b>	1.27E+05	1.68E+05	<b>2.95E+05</b>	2.43E+04	3.09E+03	5.26E+05	<b>5.53E+05</b>	1.70E+05	6.51E+04	<b>2.35E+05</b>	3.04E+04	0.00E+00	<b>3.04E+04</b>	<b>1.79E+06</b>	<b>1.82E+06</b>
Nitrous oxides	g	4.60E+02	9.00E+00	<b>4.69E+02</b>	1.77E+00	1.36E+01	<b>1.54E+01</b>	2.84E-01	2.17E-01	2.96E-02	<b>5.31E-01</b>	1.70E-04	5.58E+00	<b>5.58E+00</b>	1.18E+02	0.00E+00	<b>1.18E+02</b>	<b>4.91E+02</b>	<b>6.09E+02</b>
NM VOC, non-methane volatile organic compounds, unspecified origin	g	1.20E+04	0.00E+00	<b>1.20E+04</b>	1.92E+01	0.00E+00	<b>1.92E+01</b>	1.52E+03	0.00E+00	0.00E+00	<b>1.52E+03</b>	1.11E-05	0.00E+00	<b>1.11E-05</b>	3.58E+03	0.00E+00	<b>3.58E+03</b>	<b>1.36E+04</b>	<b>1.72E+04</b>
Organic acids	g	3.33E-01	0.00E+00	<b>3.33E-01</b>	2.38E-03	0.00E+00	<b>2.38E-03</b>	2.90E-01	0.00E+00	7.80E-01	<b>1.07E+00</b>	2.44E-03	0.00E+00	<b>2.44E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.41E+00</b>	<b>1.41E+00</b>
Organic substances, unspecified	g	8.86E+01	0.00E+00	<b>8.86E+01</b>	4.58E+00	0.00E+00	<b>4.58E+00</b>	3.15E+00	0.00E+00	3.18E+02	<b>3.21E+02</b>	9.92E-01	0.00E+00	<b>9.92E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.15E+02</b>	<b>4.15E+02</b>
Other	g	5.49E+01	0.00E+00	<b>5.49E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	5.49E+01	0.00E+00	0.00E+00	<b>5.49E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.10E+02</b>	<b>1.10E+02</b>
PAH, polycyclic aromatic hydrocarbons	g	5.25E+01	0.00E+00	<b>5.25E+01</b>	1.71E+00	0.00E+00	<b>1.71E+00</b>												

Propanal	g	4.26E+00	0.00E+00	<b>4.26E+00</b>	2.26E-01	0.00E+00	<b>2.26E-01</b>	1.46E-02	0.00E+00	2.97E-05	<b>1.46E-02</b>	1.71E-07	0.00E+00	<b>1.71E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.50E+00</b>	<b>4.50E+00</b>
Propane	g	1.79E+01	0.00E+00	<b>1.79E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.79E+01	0.00E+00	0.00E+00	<b>1.79E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.58E+01</b>	<b>3.58E+01</b>
Propene	g	4.48E+00	0.00E+00	<b>4.48E+00</b>	2.62E+01	0.00E+00	<b>2.62E+01</b>	3.09E+00	0.00E+00	0.00E+00	<b>3.09E+00</b>	1.36E+02	0.00E+00	<b>1.36E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.69E+02</b>	<b>1.69E+02</b>
Propionic acid	g	1.24E-03	0.00E+00	<b>1.24E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.24E-03	0.00E+00	0.00E+00	<b>1.24E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.48E-03</b>	<b>2.48E-03</b>
Propylene oxide	g	3.46E-04	0.00E+00	<b>3.46E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.46E-04	0.00E+00	0.00E+00	<b>3.46E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.91E-04</b>	<b>6.91E-04</b>
Pyrene	g	4.82E-03	0.00E+00	<b>4.82E-03</b>	2.49E-04	0.00E+00	<b>2.49E-04</b>	1.65E-04	0.00E+00	1.73E-02	<b>1.75E-02</b>	5.41E-05	0.00E+00	<b>5.41E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.26E-02</b>	<b>2.26E-02</b>
Radioactive species, unspecified	MBq	1.93E+02	0.00E+00	<b>1.93E+02</b>	9.18E+00	0.00E+00	<b>9.18E+00</b>	2.62E+01	0.00E+00	2.97E+03	<b>3.00E+03</b>	9.29E+00	0.00E+00	<b>9.29E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.21E+03</b>	<b>3.21E+03</b>
Radionuclides (Including Radon)	g	2.43E+03	0.00E+00	<b>2.43E+03</b>	1.73E+01	0.00E+00	<b>1.73E+01</b>	2.11E+03	0.00E+00	5.69E+03	<b>7.80E+03</b>	1.78E+01	0.00E+00	<b>1.78E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.03E+04</b>	<b>1.03E+04</b>
Selenium	g	1.96E+01	0.00E+00	<b>1.96E+01</b>	1.01E+00	0.00E+00	<b>1.01E+00</b>	6.70E-01	0.00E+00	7.60E+01	<b>7.67E+01</b>	2.57E-01	0.00E+00	<b>2.57E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>9.75E+01</b>	<b>9.75E+01</b>
Styrene	g	2.80E-01	0.00E+00	<b>2.80E-01</b>	1.49E-02	0.00E+00	<b>1.49E-02</b>	9.89E-04	0.00E+00	1.95E-06	<b>9.91E-04</b>	1.12E-08	0.00E+00	<b>1.12E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.96E-01</b>	<b>2.96E-01</b>
Sulfur dioxide	g	8.36E+05	1.33E+02	<b>8.36E+05</b>	3.34E+04	2.04E+02	<b>3.36E+04</b>	6.05E+04	3.45E+00	2.66E+06	<b>2.72E+06</b>	8.38E+03	8.17E+01	<b>8.46E+03</b>	4.02E+04	0.00E+00	<b>4.02E+04</b>	<b>3.60E+06</b>	<b>3.64E+06</b>
Sulfur hexafluoride	g	6.29E-04	0.00E+00	<b>6.29E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.29E-04	0.00E+00	0.00E+00	<b>6.29E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.26E-03</b>	<b>1.26E-03</b>
Sulfur oxides	g	6.95E+04	5.38E+03	<b>7.49E+04</b>	1.05E+04	8.23E+03	<b>1.87E+04</b>	4.23E+03	1.50E+02	9.24E+04	<b>9.67E+04</b>	8.85E+03	3.19E+03	<b>1.20E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.02E+05</b>	<b>2.02E+05</b>
Sulfur trioxide	g	1.28E-05	0.00E+00	<b>1.28E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.28E-05	0.00E+00	0.00E+00	<b>1.28E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.56E-05</b>	<b>2.56E-05</b>
Sulfuric acid	g	2.90E-06	0.00E+00	<b>2.90E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.90E-06	0.00E+00	0.00E+00	<b>2.90E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.81E-06</b>	<b>5.81E-06</b>
Sulfuric acid, dimethyl ester	g	5.37E-01	0.00E+00	<b>5.37E-01</b>	2.85E-02	0.00E+00	<b>2.85E-02</b>	1.85E-03	0.00E+00	3.75E-06	<b>1.85E-03</b>	2.16E-08	0.00E+00	<b>2.16E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.68E-01</b>	<b>5.68E-01</b>
t-Butyl methyl ether	g	3.92E-01	0.00E+00	<b>3.92E-01</b>	2.08E-02	0.00E+00	<b>2.08E-02</b>	1.59E-03	0.00E+00	2.73E-06	<b>1.59E-03</b>	1.57E-08	0.00E+00	<b>1.57E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.15E-01</b>	<b>4.15E-01</b>
Tar	g	1.40E-08	0.00E+00	<b>1.40E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.40E-08	0.00E+00	0.00E+00	<b>1.40E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.79E-08</b>	<b>2.79E-08</b>
Terpenes	g	2.53E-04	0.00E+00	<b>2.53E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.53E-04	0.00E+00	0.00E+00	<b>2.53E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.07E-04</b>	<b>5.07E-04</b>
TOC, Total Organic Carbon	g	1.31E+01	0.00E+00	<b>1.31E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.31E+01	0.00E+00	0.00E+00	<b>1.31E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.63E+01</b>	<b>2.63E+01</b>
Toluene	g	4.06E+00	0.00E+00	<b>4.06E+00</b>	4.30E+00	0.00E+00	<b>4.30E+00</b>	1.16E+00	0.00E+00	1.88E-05	<b>1.16E+00</b>	2.15E+01	0.00E+00	<b>2.15E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.10E+01</b>	<b>3.10E+01</b>
Toluene, 2,4-dinitro-	g	3.14E-03	0.00E+00	<b>3.14E-03</b>	1.66E-04	0.00E+00	<b>1.66E-04</b>	1.07E-05	0.00E+00	2.19E-08	<b>1.07E-05</b>	1.26E-10	0.00E+00	<b>1.26E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.31E-03</b>	<b>3.31E-03</b>
Toluene, 2-chloro-	g	4.76E-07	0.00E+00	<b>4.76E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.76E-07	0.00E+00	0.00E+00	<b>4.76E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>9.52E-07</b>	<b>9.52E-07</b>
Trimethylamine	g	1.52E-09	0.00E+00	<b>1.52E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.52E-09	0.00E+00	0.00E+00	<b>1.52E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.04E-09</b>	<b>3.04E-09</b>
Vinyl acetate	g	8.51E-02	0.00E+00	<b>8.51E-02</b>	4.52E-03	0.00E+00	<b>4.52E-03</b>	2.91E-04	0.00E+00	5.94E-07	<b>2.91E-04</b>	3.42E-09	0.00E+00	<b>3.42E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.99E-02</b>	<b>8.99E-02</b>
VOC, volatile organic compounds	g	1.14E+04	2.91E+03	<b>1.43E+04</b>	1.14E+04	4.69E+03	<b>1.61E+04</b>	1.82E+03	1.06E+02	4.15E+04	<b>4.34E+04</b>	4.42E+03	1.61E+03	<b>6.03E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.99E+04</b>	<b>7.99E+04</b>
Xylene	g	1.28E+00	0.00E+00	<b>1.28E+00</b>	2.92E+00	0.00E+00	<b>2.92E+00</b>	7.12E-01	0.00E+00	2.89E-06	<b>7.12E-01</b>	1.50E+01	0.00E+00	<b>1.50E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.99E+01</b>	<b>1.99E+01</b>
Zinc	g	9.84E-02	0.00E+00	<b>9.84E-02</b>	8.69E-04	0.00E+00	<b>8.69E-04</b>	8.43E-02	0.00E+00	2.00E+00	<b>2.08E+00</b>	1.15E-02	0.00E+00	<b>1.15E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.19E+00</b>	<b>2.19E+00</b>

## Appendix C5

### Absolute Values - Water Emissions for Concrete Building

		PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS	
Emission	Unit	Manufacturing	Transport	Total	Construction- Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
2-Hexanone	mg	4.30E+02	6.86E+01	4.99E+02	3.33E+01	1.04E+02	1.37E+02	3.89E+01	1.77E+00	1.94E+03	1.98E+03	7.36E+01	4.16E+01	1.15E+02	0.00E+00	0.00E+00	0.00E+00	2.73E+03	2.73E+03
Acetone	mg	6.58E+02	1.05E+02	7.64E+02	5.09E+01	1.59E+02	2.10E+02	5.96E+01	2.71E+00	2.96E+03	3.03E+03	1.13E+02	6.37E+01	1.76E+02	0.00E+00	0.00E+00	0.00E+00	4.18E+03	4.18E+03
Acids, unspecified	mg	9.61E+02	0.00E+00	9.61E+02	0.00E+00	0.00E+00	0.00E+00	9.61E+02	0.00E+00	0.00E+00	9.61E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.92E+03	1.92E+03
Aluminum	mg	3.78E+06	9.43E+05	4.72E+06	3.56E+05	1.43E+06	1.79E+06	2.89E+05	2.43E+04	1.31E+07	1.34E+07	9.68E+05	5.71E+05	1.54E+06	0.00E+00	0.00E+00	0.00E+00	2.15E+07	2.15E+07
Ammonia	mg	1.97E+06	2.00E+05	2.17E+06	9.65E+04	3.04E+05	4.00E+05	7.95E+04	5.17E+03	4.38E+06	4.46E+06	2.11E+05	1.21E+05	3.32E+05	5.23E+04	0.00E+00	0.00E+00	7.36E+06	7.41E+06
Ammonia, as N	mg	1.31E-04	0.00E+00	1.31E-04	0.00E+00	0.00E+00	0.00E+00	1.31E-04	0.00E+00	0.00E+00	1.31E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.62E-04	2.62E-04
Ammonium, ion	mg	1.75E+05	0.00E+00	1.75E+05	5.51E+03	0.00E+00	5.51E+03	1.07E+06	0.00E+00	0.00E+00	1.07E+06	2.17E+02	0.00E+00	2.17E+02	0.00E+00	0.00E+00	0.00E+00	1.25E+06	1.25E+06
Antimony	mg	2.30E+03	5.89E+02	2.89E+03	2.20E+02	8.93E+02	1.11E+03	1.52E+02	1.52E+01	8.14E+03	8.31E+03	6.05E+02	3.57E+02	9.62E+02	0.00E+00	0.00E+00	0.00E+00	1.33E+04	1.33E+04
Arsenic, ion	mg	1.65E+04	2.91E+03	1.94E+04	1.33E+03	4.41E+03	5.74E+03	2.47E+03	7.51E+01	7.15E+04	7.40E+04	3.09E+03	1.76E+03	4.85E+03	0.00E+00	0.00E+00	0.00E+00	1.04E+05	1.04E+05
Barium	mg	5.06E+07	1.29E+07	6.36E+07	4.88E+06	1.96E+07	2.44E+07	2.51E+06	3.33E+05	1.86E+08	1.89E+08	1.33E+07	7.82E+06	2.11E+07	0.00E+00	0.00E+00	0.00E+00	2.98E+08	2.98E+08
Benzene	mg	1.18E+05	1.76E+04	1.36E+05	8.55E+03	2.67E+04	3.53E+04	1.77E+04	4.55E+02	4.97E+05	5.15E+05	1.89E+04	1.07E+04	2.96E+04	0.00E+00	0.00E+00	0.00E+00	7.16E+05	7.16E+05
Benzene, 1-methyl-4-(1-methylethyl)-	µg	6.58E+03	1.05E+03	7.63E+03	5.09E+02	1.59E+03	2.10E+03	5.96E+02	2.71E+01	2.96E+04	3.02E+04	1.13E+03	6.37E+02	1.76E+03	0.00E+00	0.00E+00	0.00E+00	4.17E+04	4.17E+04
Benzene, ethyl-	mg	6.41E+03	9.92E+02	7.40E+03	4.81E+02	1.50E+03	1.98E+03	7.59E+02	2.56E+01	2.80E+04	2.88E+04	1.06E+03	6.01E+02	1.67E+03	0.00E+00	0.00E+00	0.00E+00	3.98E+04	3.98E+04
Benzene, pentamethyl-	µg	4.93E+03	7.88E+02	5.72E+03	3.82E+02	1.19E+03	1.58E+03	4.47E+02	2.03E+01	2.22E+04	2.27E+04	8.45E+02	4.77E+02	1.32E+03	0.00E+00	0.00E+00	0.00E+00	3.13E+04	3.13E+04
Benzenes, alkylated, unspecified	mg	1.98E+03	5.17E+02	2.49E+03	1.93E+02	7.84E+02	9.77E+02	9.21E+01	1.33E+01	7.14E+03	7.24E+03	5.31E+02	3.13E+02	8.44E+02	0.00E+00	0.00E+00	0.00E+00	1.16E+04	1.16E+04
Benzoic acid	mg	6.68E+04	1.07E+04	7.75E+04	5.17E+03	1.62E+04	2.13E+04	6.05E+03	2.75E+02	3.01E+05	3.07E+05	1.14E+04	6.46E+03	1.79E+04	0.00E+00	0.00E+00	0.00E+00	4.24E+05	4.24E+05
Beryllium	mg	8.49E+02	1.63E+02	1.01E+03	7.10E+01	2.47E+02	3.18E+02	6.81E+01	4.21E+00	3.56E+03	3.63E+03	1.72E+02	9.89E+01	2.71E+02	0.00E+00	0.00E+00	0.00E+00	5.23E+03	5.23E+03
Biphenyl	µg	1.28E+05	3.35E+04	1.61E+05	1.25E+04	5.07E+04	6.32E+04	5.96E+03	8.64E+02	4.62E+05	4.69E+05	3.44E+04	2.03E+04	5.46E+04	0.00E+00	0.00E+00	0.00E+00	7.48E+05	7.48E+05
BOD5, Biological Oxygen Demand	mg	2.03E+07	1.93E+06	2.22E+07	9.24E+05	2.92E+06	3.85E+06	7.38E+07	4.98E+04	5.26E+07	1.26E+08	2.08E+06	1.17E+06	3.24E+06	2.45E+05	0.00E+00	2.45E+05	1.56E+08	1.56E+08
Boron	mg	2.07E+05	3.30E+04	2.40E+05	1.60E+04	5.00E+04	6.60E+04	2.41E+04	8.52E+02	9.30E+05	9.55E+05	3.54E+04	2.00E+04	5.54E+04	0.00E+00	0.00E+00	0.00E+00	1.32E+06	1.32E+06
Bromide	mg	1.41E+07	2.25E+06	1.64E+07	1.09E+06	3.41E+06	4.51E+06	1.28E+06	5.81E+04	6.35E+07	6.48E+07	2.42E+06	1.36E+06	3.78E+06	0.00E+00	0.00E+00	0.00E+00	8.95E+07	8.95E+07
Cadmium, ion	mg	4.41E+03	4.29E+02	4.84E+03	2.05E+02	6.51E+02	8.56E+02	7.17E+02	1.11E+01	1.05E+04	1.12E+04	4.55E+02	2.60E+02	7.16E+02	4.30E+02	0.00E+00	4.30E+02	1.76E+04	1.80E+04
Calcium, ion	mg	2.23E+08	3.38E+07	2.57E+08	1.64E+07	5.12E+07	6.76E+07	3.13E+07	8.72E+05	9.52E+08	9.84E+08	3.62E+07	2.05E+07	5.67E+07	0.00E+00	0.00E+00	0.00E+00	1.37E+09	1.37E+09
Chloride	mg	2.51E+09	3.80E+08	2.89E+09	1.88E+08	5.76E+08	7.64E+08	2.75E+08	9.80E+06	1.07E+10	1.10E+10	4.07E+08	2.30E+08	6.37E+08	0.00E+00	0.00E+00	0.00E+00	1.53E+10	1.53E+10
Chromium	mg	8.53E+04	2.52E+04	1.10E+05	8.77E+03	3.81E+04	4.69E+04	2.03E+03	6.49E+02	2.57E+05	2.60E+05	2.55E+04	1.52E+04	4.08E+04	-7.82E+02	0.00E+00	-7.82E+02	4.58E+05	4.57E+05
Chromium VI	µg	7.33E+05	1.06E+05	8.39E+05	3.66E+04	1.60E+05	1.97E+05	4.09E+05	2.73E+03	1.08E+06	1.49E+06	1.07E+05	6.41E+04	1.72E+05	0.00E+00	0.00E+00	0.00E+00	2.70E+06	2.70E+06
Chromium, ion	mg	2.15E+04	1.63E+03	2.31E+04	1.30E+03	2.47E+03	3.77E+03	2.74E+03	4.21E+01	1.12E+05	1.15E+05	1.96E+03	9.88E+02	2.95E+03	0.00E+00	0.00E+00	0.00E+00	1.45E+05	1.45E+05
Cobalt	mg	1.72E+03	2.33E+02	1.96E+03	1.13E+02	3.53E+02	4.66E+02	6.11E+02	6.01E+00	6.57E+03	7.18E+03	2.50E+02	1.41E+02	3.91E+02	0.00E+00	0.00E+00	0.00E+00	1.00E+04	1.00E+04
COD, Chemical Oxygen Demand	mg	4.38E+07	3.68E+06	4.75E+07	1.98E+06	5.58E+06	7.56E+06	2.77E+08	9.51E+04	9.20E+07	3.69E+08	3.97E+06	2.23E+06	6.20E+06	-1.74E+05	0.00E+00	-1.74E+05	4.31E+08	4.31E+08
Copper, ion	mg	1.69E+04	3.03E+03	1.99E+04	1.27E+03	4.59E+03	5.85E+03	1.35E+04	7.81E+01	5.87E+04	7.23E+04	3.17E+03	1.83E+03	5.00E+03	0.00E+00	0.00E+00	0.00E+00	1.03E+05	1.03E+05
Cyanide	mg	3.34E+04	7.59E-01	3.34E+04	1.46E+03	1.15E+00	1.46E+03	5.60E+03	1.96E-02	2.14E+01	5.62E+03	8.14E-01	4.60E-01	1.27E+00	0.00E+00	0.00E+00	0.00E+00	4.05E+04	4.05E+04
Decane	mg	1.92E+03	3.06E+02	2.23E+03	1.48E+02	4.65E+02	6.13E+02	1.74E+02	7.91E+00	8.64E+03	8.82E+03	3.29E+02	1.86E+02	5.14E+02	0.00E+00	0.00E+00	0.00E+00	1.22E+04	1.22E+04
Detergent, oil	mg	6.01E+04	8.75E+03	6.88E+04	4.48E+03	1.33E+04	1.78E+04	5.80E+03	2.26E+02	2.78E+05	2.84E+05	9.49E+03	5.30E+03	1.48E+04	0.00E+00	0.00E+00	0.00E+00	3.85E+05	3.85E+05
Dibenzofuran	µg	1.25E+04	2.00E+03	1.45E+04	9.69E+02	3.03E+03	4.00E+03	1.13E+03	5.16E+01	5.64E+04	5.75E+04	2.14E+03	1.21E+03	3.36E+03	0.00E+00	0.00E+00	0.00E+00	7.94E+04	7.94E+04
Dibenzothiophene	µg	5.32E+03	1.03E+02	5.42E+03	2.60E+02	1.57E+02	4.17E+02	8.52E+02	2.67E+00	3.02E+04	3.10E+04	1.97E+02	6.26E+01	2.60E+02	0.00E+00	0.00E+00	0.00E+00	3.71E+04	3.71E+04
Dissolved solids	mg	2.91E+09	4.68E+08	3.38E+09	2.27E+08	7.10E+08	9.37E+08	2.39E+08	1.21E+07	1.32E+10	1.35E+10	5.02E+08	2.84E+08	7.86E+08	1.42E+05	0.00E+00	1.42E+05	1.86E+10	1.86E+10
DOC, Dissolved Organic Carbon	mg	2.13E+06	0.00E+00	2.13E+06	8.48E+04	0.00E+00	8.48E+04	2.49E+08	0.00E+00	0.00E+00	2.49E+08	5.42E+04	0.00E+00	5.42E+04	0.00E+00	0.00E+00	0.00E+00	2.52E+08	2.52E+08
Docosane	µg	7.05E+04	1.12E+04	8.17E+04	5.45E+03	1.71E+04	2.25E+04	6.38E+03	2.90E+02	3.17E+05	3.24E+05	1.21E+04	6.82E+03	1.89E+04	0.00E+00	0.00E+00	0.00E+00	4.47E+05	4.47E+05
Dodecane	mg	3.64E+03	5.81E+02	4.22E+03	2.82E+02	8.82E+02	1.16E+03	3.30E+02	1.50E+01	1.64E+04	1.67E+04	6.24E+02	3.52E+02	9.76E+02	0.00E+00	0.00E+00	0.00E+00	2.31E+04	2.31E+04
Eicosane	mg	1.00E+03	1.60E+02	1.16E+03	7.76E+01	2.43E+02	3.20E+02	9.08E+01	4.13E+00	4.51E+03	4.61E+03	1.72E+02	9.70E+01	2.69E+02	0.00E+00	0.00E+00	0.00E+00	6.36E+03	6.36E+03
Fluorene, 1-methyl-	µg	7.49E+03	1.20E+03	8.69E+03	5.80E+02	1.81E+03	2.39E+03	6.79E+02	3.09E+01	3.37E+04	3.44E+04	1.28E+03	7.25E+02	2.01E+03	0.00E+00	0.00E+00	0.00E+00	4.75E+04	4.75E+04
Fluorenes, alkylated, unspecified	µg	1.15E+05	2.99E+04	1.45E+05	1.12E+04	4.54E+04	5.66E+04	5.34E+03	7.73E+02	4.14E+05	4.20E+05	3.08E+04	1.81E+04	4.89E+04	0.00E+00	0.00E+00	0.00E+00	6.70E+05	6.70E+05
Fluoride	mg	1.73E+05	0.00E+00	1.73E+05	6.00E+03	0.00E+00	6.00E+03	1.11E+05	0.00E+00	0.00E+00	1.11E+05	1.13E+01	0.00E+00	1.13E+01	0.00E+00	0.00E+00	0.00E+00	2.90E+05	2.90E+05
Fluorine	µg	5.86E+04	1.47E+04	7.34E+04	5.61E+03	2.24E+04	2.80E+04	3.00E+03	3.81E+02	2.17E+05	2.20E+05	1.52E+04	8.93E+03	2.41E+04	0.00E+00	0.00E+00	0.00E+00	3.45E+05	3.45E+05
Hexadecane	mg	3.97E+03	6.35E+02	4.61E+03	3.08E+02	9.62E+02	1.27E+03	3.60E+02	1.64E+01	1.79E+04	1.83E+04	6.81E+02	3.85E+02	1.07E+03	0.00E+00	0.00E+00	0.00E+00	2.52E+04	2.52E+04

Hexanoic acid	mg	1.38E+04	2.21E+03	<b>1.60E+04</b>	1.07E+03	3.35E+03	<b>4.42E+03</b>	1.25E+03	5.70E+01	6.23E+04	<b>6.36E+04</b>	2.37E+03	1.34E+03	<b>3.71E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.77E+04	8.77E+04
Hydrocarbons, unspecified	µg	5.74E+06	0.00E+00	<b>5.74E+06</b>	9.23E+03	0.00E+00	<b>9.23E+03</b>	5.57E+06	0.00E+00	0.00E+00	<b>5.57E+06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.13E+07	1.13E+07
Hydrogen sulfide	mg	6.44E+01	0.00E+00	<b>6.44E+01</b>	2.50E-01	0.00E+00	<b>2.50E-01</b>	2.24E+04	0.00E+00	0.00E+00	<b>2.24E+04</b>	4.87E+00	0.00E+00	<b>4.87E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.25E+04	2.25E+04
Iron	mg	2.95E+07	1.87E+06	<b>3.14E+07</b>	1.00E+06	2.83E+06	<b>3.83E+06</b>	5.59E+05	4.82E+04	3.09E+07	<b>3.15E+07</b>	1.93E+06	1.13E+06	<b>3.06E+06</b>	-1.69E+06	0.00E+00	<b>-1.69E+06</b>	6.98E+07	6.81E+07
Lead	mg	3.80E+04	6.19E+03	<b>4.41E+04</b>	2.71E+03	9.38E+03	<b>1.21E+04</b>	7.42E+04	1.60E+02	1.23E+05	<b>1.98E+05</b>	6.49E+03	3.75E+03	<b>1.02E+04</b>	-2.26E+03	0.00E+00	<b>-2.26E+03</b>	2.64E+05	2.62E+05
Lead-210/kg	µg	8.48E+07	1.09E-03	<b>8.48E+07</b>	5.29E-04	1.65E-03	<b>2.18E-03</b>	8.48E+07	2.82E-05	3.08E-02	<b>8.48E+07</b>	1.17E-03	6.61E-04	<b>1.83E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.70E+08	1.70E+08
Lithium, ion	mg	3.44E+07	1.13E+04	<b>3.44E+07</b>	1.57E+06	1.71E+04	<b>1.58E+06</b>	5.49E+06	2.91E+02	2.03E+08	<b>2.08E+08</b>	6.56E+05	6.84E+03	<b>6.63E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.45E+08	2.45E+08
m-Xylene	mg	1.99E+03	3.19E+02	<b>2.31E+03</b>	1.54E+02	4.83E+02	<b>6.37E+02</b>	1.81E+02	8.22E+00	8.98E+03	<b>9.17E+03</b>	3.42E+02	1.93E+02	<b>5.35E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.27E+04	1.27E+04
Magnesium	mg	4.14E+07	6.60E+06	<b>4.80E+07</b>	3.20E+06	1.00E+07	<b>1.32E+07</b>	4.26E+06	1.70E+05	1.86E+08	<b>1.91E+08</b>	7.08E+06	4.00E+06	<b>1.11E+07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.63E+08	2.63E+08
Manganese	mg	1.69E+06	1.05E+04	<b>1.70E+06</b>	1.38E+04	1.60E+04	<b>2.98E+04</b>	1.60E+06	2.72E+02	8.95E+05	<b>2.49E+06</b>	1.32E+04	6.38E+03	<b>1.96E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.25E+06	4.25E+06
Mercury	µg	4.09E+04	1.03E+04	<b>5.12E+04</b>	3.87E+03	1.57E+04	<b>1.95E+04</b>	7.89E+05	2.67E+02	1.43E+05	<b>9.32E+05</b>	1.08E+04	6.26E+03	<b>1.70E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.02E+06	1.02E+06
Metallic ions, unspecified	mg	1.77E+05	0.00E+00	<b>1.77E+05</b>	6.00E+03	0.00E+00	<b>6.00E+03</b>	6.33E+04	0.00E+00	0.00E+00	<b>6.33E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.47E+05	2.47E+05
Methane, monochloro-, R-40	µg	2.65E+03	4.23E+02	<b>3.07E+03</b>	2.05E+02	6.42E+02	<b>8.47E+02</b>	2.40E+02	1.09E+01	1.19E+04	<b>1.22E+04</b>	4.54E+02	2.56E+02	<b>7.10E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.68E+04	1.68E+04
Methyl ethyl ketone	µg	5.30E+03	8.46E+02	<b>6.15E+03</b>	4.10E+02	1.28E+03	<b>1.69E+03</b>	4.80E+02	2.18E+01	2.39E+04	<b>2.44E+04</b>	9.08E+02	5.13E+02	<b>1.42E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.36E+04	3.36E+04
Molybdenum	mg	1.55E+03	2.42E+02	<b>1.79E+03</b>	1.17E+02	3.66E+02	<b>4.84E+02</b>	9.83E+02	6.24E+00	6.81E+03	<b>7.80E+03</b>	2.59E+02	1.46E+02	<b>4.06E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.05E+04	1.05E+04
n-Hexacosane	µg	4.40E+04	7.02E+03	<b>5.10E+04</b>	3.40E+03	1.06E+04	<b>1.40E+04</b>	3.98E+03	1.81E+02	1.98E+05	<b>2.02E+05</b>	7.53E+03	4.25E+03	<b>1.18E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.79E+05	2.79E+05
Naphthalene	mg	1.19E+03	1.92E+02	<b>1.38E+03</b>	9.27E+01	2.90E+02	<b>3.83E+02</b>	1.03E+02	4.95E+00	5.39E+03	<b>5.50E+03</b>	2.05E+02	1.16E+02	<b>3.22E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.59E+03	7.59E+03
Naphthalene, 2-methyl-	mg	1.04E+03	1.67E+02	<b>1.21E+03</b>	8.07E+01	2.52E+02	<b>3.33E+02</b>	9.45E+01	4.30E+00	4.69E+03	<b>4.79E+03</b>	1.79E+02	1.01E+02	<b>2.80E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.62E+03	6.62E+03
Naphthalenes, alkylated, unspecified	µg	3.24E+04	8.47E+03	<b>4.09E+04</b>	3.17E+03	1.28E+04	<b>1.60E+04</b>	1.51E+03	2.19E+02	1.17E+05	<b>1.19E+05</b>	8.70E+03	5.13E+03	<b>1.38E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.89E+05	1.89E+05
Nickel	mg	1.88E+04	2.89E+03	<b>2.17E+04</b>	1.26E+03	4.38E+03	<b>5.64E+03</b>	2.91E+03	7.46E+01	6.26E+04	<b>6.56E+04</b>	3.04E+03	1.75E+03	<b>4.79E+03</b>	1.37E+03	0.00E+00	<b>1.37E+03</b>	9.77E+04	9.91E+04
Nitrate	mg	7.01E+05	0.00E+00	<b>7.01E+05</b>	3.42E+04	0.00E+00	<b>3.42E+04</b>	3.35E+05	0.00E+00	0.00E+00	<b>3.35E+05</b>	5.69E+01	0.00E+00	<b>5.69E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.07E+06	1.07E+06
Nitrate compounds	mg	3.54E-06	0.00E+00	<b>3.54E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.54E-06	0.00E+00	0.00E+00	<b>3.54E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.07E-06	7.07E-06
Nitric acid	mg	7.93E-03	0.00E+00	<b>7.93E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.93E-03	0.00E+00	0.00E+00	<b>7.93E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.59E-02	1.59E-02
Nitrogen	mg	9.99E+04	0.00E+00	<b>9.99E+04</b>	-6.52E+04	0.00E+00	<b>-6.52E+04</b>	1.59E+06	0.00E+00	0.00E+00	<b>1.59E+06</b>	3.40E+02	0.00E+00	<b>3.40E+02</b>	2.74E+06	0.00E+00	<b>2.74E+06</b>	1.62E+06	4.37E+06
o-Cresol	mg	1.89E+03	3.02E+02	<b>2.20E+03</b>	1.47E+02	4.59E+02	<b>6.05E+02</b>	1.72E+02	7.81E+00	8.53E+03	<b>8.70E+03</b>	3.24E+02	1.83E+02	<b>5.08E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.20E+04	1.20E+04
Octadecane	mg	9.82E+02	1.57E+02	<b>1.14E+03</b>	7.60E+01	2.38E+02	<b>3.14E+02</b>	8.89E+01	4.05E+00	4.42E+03	<b>4.51E+03</b>	1.68E+02	9.50E+01	<b>2.63E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.23E+03	6.23E+03
Oils, unspecified	mg	3.63E+06	2.44E+05	<b>3.88E+06</b>	1.86E+05	3.70E+05	<b>5.56E+05</b>	9.81E+05	6.31E+03	6.35E+06	<b>7.34E+06</b>	2.60E+05	1.48E+05	<b>4.08E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.22E+07	1.22E+07
Other	mg	2.31E+07	0.00E+00	<b>2.31E+07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.31E+07	0.00E+00	0.00E+00	<b>2.31E+07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.62E+07	4.62E+07
Other metals	mg	2.87E+06	0.00E+00	<b>2.87E+06</b>	2.59E+02	0.00E+00	<b>2.59E+02</b>	2.86E+06	0.00E+00	0.00E+00	<b>2.86E+06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	5.73E+06	5.73E+06
p-Cresol	mg	2.04E+03	3.26E+02	<b>2.37E+03</b>	1.58E+02	4.95E+02	<b>6.53E+02</b>	1.85E+02	8.42E+00	9.20E+03	<b>9.39E+03</b>	3.50E+02	1.98E+02	<b>5.48E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.30E+04	1.30E+04
PAH, polycyclic aromatic hydrocarbons	µg	4.69E+04	0.00E+00	<b>4.69E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.69E+04	0.00E+00	0.00E+00	<b>4.69E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	9.39E+04	9.39E+04
Pentanone, methyl-	mg	2.74E+02	4.42E+01	<b>3.18E+02</b>	2.14E+01	6.70E+01	<b>8.84E+01</b>	2.25E+01	1.14E+00	1.25E+03	<b>1.27E+03</b>	4.74E+01	2.68E+01	<b>7.42E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.75E+03	1.75E+03
Phenanthrene	µg	1.38E+04	3.00E+03	<b>1.68E+04</b>	1.22E+03	4.55E+03	<b>5.77E+03</b>	8.98E+02	7.74E+01	5.49E+04	<b>5.58E+04</b>	3.12E+03	1.82E+03	<b>4.94E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.33E+04	8.33E+04
Phenanthrenes, alkylated, unspecified	µg	1.34E+04	3.51E+03	<b>1.69E+04</b>	1.31E+03	5.32E+03	<b>6.64E+03</b>	6.26E+02	9.06E+01	4.85E+04	<b>4.92E+04</b>	3.61E+03	2.13E+03	<b>5.73E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.85E+04	7.85E+04
Phenol	µg	2.92E+07	4.68E+06	<b>3.39E+07</b>	2.32E+06	7.10E+06	<b>9.42E+06</b>	1.31E+06	1.21E+05	4.79E+07	<b>4.93E+07</b>	4.76E+06	2.84E+06	<b>7.59E+06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.00E+08	1.00E+08
Phenol, 2,4-dimethyl-	mg	1.84E+03	2.94E+02	<b>2.14E+03</b>	1.43E+02	4.46E+02	<b>5.89E+02</b>	1.67E+02	7.60E+00	8.30E+03	<b>8.48E+03</b>	3.16E+02	1.78E+02	<b>4.94E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.17E+04	1.17E+04
Phenols, unspecified	mg	1.65E+04	6.58E+02	<b>1.72E+04</b>	8.79E+02	9.97E+02	<b>1.88E+03</b>	2.40E+03	1.70E+01	9.12E+04	<b>9.37E+04</b>	9.37E+02	3.99E+02	<b>1.34E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.14E+05	1.14E+05
Phosphate	mg	3.97E+04	0.00E+00	<b>3.97E+04</b>	3.20E+02	0.00E+00	<b>3.20E+02</b>	2.33E+04	0.00E+00	0.00E+00	<b>2.33E+04</b>	1.27E+00	0.00E+00	<b>1.27E+00</b>	-3.95E+03	0.00E+00	<b>-3.95E+03</b>	6.34E+04	5.94E+04
Phosphorus	mg	7.16E+03	0.00E+00	<b>7.16E+03</b>	3.12E+02	0.00E+00	<b>3.12E+02</b>	6.18E+03	0.00E+00	0.00E+00	<b>6.18E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-1.20E+04	0.00E+00	<b>-1.20E+04</b>	1.37E+04	1.67E+03
Radioactive species, Nuclides, unspecified	mg	1.79E+08	0.00E+00	<b>1.79E+08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.79E+08	0.00E+00	0.00E+00	<b>1.79E+08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.58E+08	3.58E+08
Radium-226/kg	µg	2.37E+00	3.80E-01	<b>2.75E+00</b>	1.84E-01	5.76E-01	<b>7.60E-01</b>	2.08E-01	9.81E-03	1.07E+01	<b>1.09E+01</b>	4.08E-01	2.30E-01	<b>6.38E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.51E+01	1.51E+01
Radium-228/kg	µg	1.21E-02	1.94E-03	<b>1.41E-02</b>	9.42E-04	2.94E-03	<b>3.88E-03</b>	1.06E-03	5.01E-05	5.48E-02	<b>5.59E-02</b>	2.09E-03	1.18E-03	<b>3.26E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.71E-02	7.71E-02
Selenium	µg	4.60E+05	1.14E+05	<b>5.74E+05</b>	4.28E+04	1.73E+05	<b>2.16E+05</b>	4.19E+04	2.95E+03	1.59E+06	<b>1.63E+06</b>	1.17E+05	6.92E+04	<b>1.87E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.61E+06	2.61E+06
Silver	mg	1.38E+05	2.21E+04	<b>1.60E+05</b>	1.07E+04	3.35E+04	<b>4.42E+04</b>	1.25E+04	5.70E+02	6.22E+05	<b>6.35E+05</b>	2.37E+04	1.34E+04	<b>3.71E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.76E+05	8.76E+05
Sodium, ion	mg	6.73E+08	1.07E+08	<b>7.80E+08</b>	5.19E+07	1.62E+08	<b>2.14E+08</b>	6.33E+07	2.76E+06	3.02E+09	<b>3.09E+09</b>	1.15E+08	6.49E+07	<b>1.80E+08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.26E+09	4.26

Tetradecane	mg	1.60E+03	2.55E+02	<b>1.85E+03</b>	1.23E+02	3.86E+02	<b>5.10E+02</b>	1.45E+02	6.58E+00	7.18E+03	<b>7.33E+03</b>	2.73E+02	1.54E+02	<b>4.28E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.01E+04</b>	<b>1.01E+04</b>
Thallium	µg	4.81E+05	1.24E+05	<b>6.05E+05</b>	4.64E+04	1.88E+05	<b>2.35E+05</b>	2.78E+04	3.20E+03	1.72E+06	<b>1.75E+06</b>	1.27E+05	7.52E+04	<b>2.03E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.79E+06</b>	<b>2.79E+06</b>
Tin	mg	1.12E+04	2.36E+03	<b>1.36E+04</b>	9.78E+02	3.58E+03	<b>4.56E+03</b>	8.37E+02	6.10E+01	4.50E+04	<b>4.59E+04</b>	2.47E+03	1.43E+03	<b>3.90E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.79E+04</b>	<b>6.79E+04</b>
Titanium, ion	mg	4.95E+04	9.05E+03	<b>5.85E+04</b>	3.38E+03	1.37E+04	<b>1.71E+04</b>	1.65E+04	2.34E+02	1.25E+05	<b>1.42E+05</b>	9.29E+03	5.48E+03	<b>1.48E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.32E+05</b>	<b>2.32E+05</b>
Toluene	mg	1.05E+05	1.67E+04	<b>1.22E+05</b>	8.07E+03	2.53E+04	<b>3.33E+04</b>	1.05E+04	4.30E+02	4.70E+05	<b>4.81E+05</b>	1.79E+04	1.01E+04	<b>2.80E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.64E+05</b>	<b>6.64E+05</b>
Vanadium	mg	2.32E+03	2.85E+02	<b>2.60E+03</b>	1.38E+02	4.33E+02	<b>5.71E+02</b>	6.93E+02	7.37E+00	8.05E+03	<b>8.75E+03</b>	3.06E+02	1.73E+02	<b>4.79E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.24E+04</b>	<b>1.24E+04</b>
Xylene	mg	2.98E+04	8.73E+03	<b>3.86E+04</b>	3.05E+03	1.32E+04	<b>1.63E+04</b>	1.86E+03	2.25E+02	9.34E+04	<b>9.55E+04</b>	8.88E+03	5.29E+03	<b>1.42E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.64E+05</b>	<b>1.64E+05</b>
Yttrium	mg	4.44E+02	7.08E+01	<b>5.15E+02</b>	3.43E+01	1.07E+02	<b>1.42E+02</b>	4.02E+01	1.83E+00	2.00E+03	<b>2.04E+03</b>	7.60E+01	4.29E+01	<b>1.19E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.81E+03</b>	<b>2.81E+03</b>
Zinc	mg	8.47E+04	2.17E+04	<b>1.06E+05</b>	8.71E+03	3.29E+04	<b>4.16E+04</b>	4.10E+04	5.61E+02	3.15E+05	<b>3.57E+05</b>	2.24E+04	1.32E+04	<b>3.55E+04</b>	-2.01E+04	0.00E+00	<b>-2.01E+04</b>	<b>5.40E+05</b>	<b>5.20E+05</b>

## Appendix C6

### Absolute Values - Land Emissions for Concrete Building

		PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS	
Emission	Unit	Manufacturing	Transport	Total	Construction- Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
Bark/Wood Waste	kg	7.33E+02	0.00E+00	<b>7.33E+02</b>	8.07E+03	0.00E+00	<b>8.07E+03</b>	7.33E+02	0.00E+00	0.00E+00	<b>7.33E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>9.53E+03</b>	<b>9.53E+03</b>
Concrete Solid Waste	kg	2.24E+04	0.00E+00	<b>2.24E+04</b>	4.37E+04	0.00E+00	<b>4.37E+04</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.61E+04</b>	<b>6.61E+04</b>
Blast Furnace Dust	kg	1.66E+03	0.00E+00	<b>1.66E+03</b>	9.69E+01	0.00E+00	<b>9.69E+01</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.75E+03</b>	<b>1.75E+03</b>
Steel Waste	kg	1.73E+00	0.00E+00	<b>1.73E+00</b>	8.53E+01	0.00E+00	<b>8.53E+01</b>	1.73E+00	0.00E+00	0.00E+00	<b>1.73E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.88E+01</b>	<b>8.88E+01</b>
Other Solid Waste	kg	9.76E+03	9.32E+01	<b>9.85E+03</b>	4.96E+02	1.41E+02	<b>6.38E+02</b>	8.04E+02	2.41E+00	3.10E+04	<b>3.18E+04</b>	1.89E+02	5.65E+01	<b>2.45E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.25E+04</b>	<b>4.25E+04</b>
Solid Waste to Landfill	kg	3.03E+00	0.00E+00	<b>3.03E+00</b>	2.75E+04	0.00E+00	<b>2.75E+04</b>	2.46E+03	0.00E+00	0.00E+00	<b>2.46E+03</b>	5.36E+05	0.00E+00	<b>5.36E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.66E+05</b>	<b>5.66E+05</b>

## Appendix C7

### Absolute Values - Ecologically Weighted Resource Use for Concrete Building

		PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS	
Material	Unit	Manufacturing	Transport	Total	Construction- Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
Ash	kg	1.27E+03	0.00E+00	<b>1.27E+03</b>	7.00E+01	0.00E+00	<b>7.00E+01</b>	3.65E-05	0.00E+00	0.00E+00	<b>3.65E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.34E+03</b>	<b>1.34E+03</b>
Carbon dioxide, in air	kg	9.41E+02	0.00E+00	<b>9.41E+02</b>	6.06E+00	0.00E+00	<b>6.06E+00</b>	2.57E-01	0.00E+00	0.00E+00	<b>2.57E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.42E+02	0.00E+00	<b>1.42E+02</b>	<b>9.47E+02</b>	<b>1.09E+03</b>
Clay & Shale	kg	5.74E+04	0.00E+00	<b>5.74E+04</b>	3.17E+03	0.00E+00	<b>3.17E+03</b>	2.08E+00	0.00E+00	0.00E+00	<b>2.08E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.05E+04</b>	<b>6.05E+04</b>
Coal	kg	5.58E+04	4.14E+01	<b>5.58E+04</b>	2.07E+03	6.28E+01	<b>2.13E+03</b>	1.18E+03	1.07E+00	1.21E+05	<b>1.22E+05</b>	4.19E+02	2.51E+01	<b>4.44E+02</b>	1.66E+04	0.00E+00	<b>1.66E+04</b>	<b>1.81E+05</b>	<b>1.97E+05</b>
Coarse Aggregate	kg	5.38E+05	0.00E+00	<b>5.38E+05</b>	2.69E+04	0.00E+00	<b>2.69E+04</b>	9.77E+02	0.00E+00	0.00E+00	<b>9.77E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.66E+05</b>	<b>5.66E+05</b>
Crude Oil	L	1.19E+04	2.55E+03	<b>1.44E+04</b>	3.54E+03	3.31E+03	<b>6.84E+03</b>	4.35E+02	2.93E+01	3.57E+04	<b>3.62E+04</b>	3.47E+03	1.60E+03	<b>5.08E+03</b>	-3.49E+02	0.00E+00	<b>-3.49E+02</b>	<b>6.25E+04</b>	<b>6.22E+04</b>
Dolomite	kg	3.51E+03	0.00E+00	<b>3.51E+03</b>	1.58E+01	0.00E+00	<b>1.58E+01</b>	9.57E-01	0.00E+00	0.00E+00	<b>9.57E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.10E+02	0.00E+00	<b>8.10E+02</b>	<b>3.53E+03</b>	<b>4.34E+03</b>
Ferrous scrap	kg	6.47E+04	0.00E+00	<b>6.47E+04</b>	6.53E+02	0.00E+00	<b>6.53E+02</b>	1.76E+01	0.00E+00	0.00E+00	<b>1.76E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.53E+04</b>	<b>6.53E+04</b>
Fine Aggregate	kg	3.83E+05	0.00E+00	<b>3.83E+05</b>	2.14E+04	0.00E+00	<b>2.14E+04</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.04E+05</b>	<b>4.04E+05</b>
Gypsum (Natural)	kg	8.91E+03	0.00E+00	<b>8.91E+03</b>	4.92E+02	0.00E+00	<b>4.92E+02</b>	1.41E-07	0.00E+00	0.00E+00	<b>1.41E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>9.41E+03</b>	<b>9.41E+03</b>
Gypsum (Synthetic)	kg	1.76E-04	0.00E+00	<b>1.76E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.76E-04	0.00E+00	0.00E+00	<b>1.76E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.51E-04</b>	<b>3.51E-04</b>
Iron Ore	kg	7.47E+02	0.00E+00	<b>7.47E+02</b>	-7.07E+02	0.00E+00	<b>-7.07E+02</b>	1.15E+01	0.00E+00	0.00E+00	<b>1.15E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.18E+04	0.00E+00	<b>3.18E+04</b>	<b>5.16E+01</b>	<b>3.19E+04</b>
Lignite	kg	9.90E+02	0.00E+00	<b>9.90E+02</b>	3.70E+01	0.00E+00	<b>3.70E+01</b>	2.70E-01	0.00E+00	0.00E+00	<b>2.70E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-1.11E+03	0.00E+00	<b>-1.11E+03</b>	<b>1.03E+03</b>	<b>-8.45E+01</b>
Limestone	kg	2.09E+05	0.00E+00	<b>2.09E+05</b>	1.15E+04	0.00E+00	<b>1.15E+04</b>	1.86E+02	0.00E+00	0.00E+00	<b>1.86E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-1.25E+03	0.00E+00	<b>-1.25E+03</b>	<b>2.21E+05</b>	<b>2.19E+05</b>
Natural Gas	m3	1.73E+04	1.36E+02	<b>1.74E+04</b>	6.03E+02	2.06E+02	<b>8.10E+02</b>	1.86E+03	3.51E+00	6.27E+04	<b>6.45E+04</b>	3.29E+02	8.25E+01	<b>4.12E+02</b>	-1.72E+03	0.00E+00	<b>-1.72E+03</b>	<b>8.31E+04</b>	<b>8.14E+04</b>
Other	kg	1.10E+03	0.00E+00	<b>1.10E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.10E+03	0.00E+00	0.00E+00	<b>1.10E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.21E+03</b>	<b>2.21E+03</b>
Sand	kg	2.93E+03	0.00E+00	<b>2.93E+03</b>	1.39E+02	0.00E+00	<b>1.39E+02</b>	4.08E+02	0.00E+00	0.00E+00	<b>4.08E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.48E+03</b>	<b>3.48E+03</b>
Semi-Cementitious Material	kg	2.88E+04	0.00E+00	<b>2.88E+04</b>	1.44E+03	0.00E+00	<b>1.44E+03</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.03E+04</b>	<b>3.03E+04</b>
Tin ore	kg	5.17E-10	0.00E+00	<b>5.17E-10</b>	5.26E-12	0.00E+00	<b>5.26E-12</b>	1.41E-13	0.00E+00	0.00E+00	<b>1.41E-13</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-1.98E-12	0.00E+00	<b>-1.98E-12</b>	<b>5.22E-10</b>	<b>5.20E-10</b>
Uranium	kg	7.70E-01	3.37E-04	<b>7.71E-01</b>	7.81E-03	5.10E-04	<b>8.32E-03</b>	4.95E-01	8.69E-06	1.33E+00	<b>1.82E+00</b>	4.46E-03	2.04E-04	<b>4.67E-03</b>	-6.87E-02	0.00E+00	<b>-6.87E-02</b>	<b>2.60E+00</b>	<b>2.54E+00</b>
Water	L	9.01E+05	0.00E+00	<b>9.01E+05</b>	5.79E+03	0.00E+00	<b>5.79E+03</b>	1.23E+04	0.00E+00	0.00E+00	<b>1.23E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.94E+05	0.00E+00	<b>2.94E+05</b>	<b>9.19E+05</b>	<b>1.21E+06</b>
Wood Fiber	kg	2.25E+03	0.00E+00	<b>2.25E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.25E+03	0.00E+00	0.00E+00	<b>2.25E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.51E+03</b>	<b>4.51E+03</b>

## Appendix S1

### Bill of Materials Steel Building

Material	Unit	Total Quantity	Columns & Beams	Floors	Foundations	Roofs	Walls	Mass Value	Mass Unit
Aluminum	Tonnes	0.4112	0	0	0	0	0.4112	0.4112	Tonnes
Aluminum Clad Wood Window Frame	kg	1098.9969	0	0	0	0	1098.9969	1.099	Tonnes
Concrete 20 MPa (flyash av)	m3	85.4928	0	0	85.4928	0	0	198.7708	Tonnes
Concrete 30 MPa (flyash av)	m3	219.6872	0	146.4581	0	73.2291	0	510.7727	Tonnes
Double Glazed Hard Coated Air	m2	186.3118	0	0	0	0	186.3118	3.017	Tonnes
Galvanized Decking	Tonnes	19.29	0	12.86	0	6.43	0	19.29	Tonnes
Galvanized Studs	Tonnes	8.6541	0	0	0	0	8.6541	8.6541	Tonnes
Glazing Panel	Tonnes	0.8112	0	0	0	0	0.8112	0.8112	Tonnes
Hollow Structural Steel	Tonnes	3.3117	3.3117	0	0	0	0	3.3117	Tonnes
Nails	Tonnes	0.0313	0	0	0	0	0.0313	0.0313	Tonnes
Rebar, Rod, Light Sections	Tonnes	0.1776	0	0	0.1776	0	0	0.1776	Tonnes
Screws Nuts & Bolts	Tonnes	2.3999	1.5901	0.3565	0	0.1783	0.275	2.3999	Tonnes
Softwood Plywood	m2 (9mm)	2525.6283	0	0	0	0	2525.6283	11.931	Tonnes
Welded Wire Mesh / Ladder Wire	Tonnes	2.9552	0	1.6719	0.4473	0.836	0	2.9552	Tonnes
Wide Flange Sections	Tonnes	70.7421	27.8737	28.5789	0	14.2895	0	70.7421	Tonnes

## Appendix-S2

### Structural Detailing of Steel Building

#### 1- Details of Foundations

Sr. No.	Assembly	Length	Width	Thickness	Rebar	Concrete
		(m)	(m)	(mm)		(Mpa)
1	Footings to Columns	32	2	500	#15 M	20
2	Slab for Ground Floor	22.5	22	100	-	20

#### 2- Details of Columns & Beams

Sr. No.	Assembly	No. of Columns	Column Height	Column Type	No. of Beams	Beam Type	Bay Size	Supported Span	Supported Area	Supported Element	Live Load
			(m)				(m)	(m)	(m <sup>2</sup> )		(kPa)
1	Ground Floor Column & Beam	12	3.6	Hollow Structural Steel	9	Wide Flanged Steel Beam	9.15	9.1	500	Floor	3.6
2	First Floor Column & Beam	12	3.6	Hollow Structural Steel	9	Wide Flanged Steel Beam	9.15	9.1	500	Floor	3.6
3	Second Floor Column & Beam	12	3.6	Hollow Structural Steel	9	Wide Flanged Steel Beam	9.15	9.1	500	Floor	2.4

#### 3- Details of Floors

Sr. No.	Assembly	No. of Bays per Row	No. of Rows	Bay Size	Span	Concrete	Live Load	Floor Area
				(m)	(m)	Mpa	kPa	(m <sup>2</sup> )
1	First Floor Slab	2	3	9.15	9.1	30	3.6	500
2	Second Floor Slab	2	3	9.15	9.1	3	3.6	500

#### 4- Details of Walls

Sr. No.	Assembly	Type	Wall Type	Length	Height	Stud Thickness	Sheathing Type	Stud weight	No. of Windows	Total Window Area	No. of Doors	Material for Door and Windows
				(m)	(m)			(Ga)		(m <sup>2</sup> )	(32" x 7")	
1	Ground Floor Exterior Walls	Steel Stud - Exterior Infill Wall	Non Load Bearing	178	3.6	39 x 92	Plywood	20	10	25	4	Aluminum
2	First Floor Exterior Walls	Steel Stud - Exterior Infill Wall	Non Load Bearing	178	3.6	39 x 92	Plywood	20	15	37.5	2	Aluminum
3	Second Floor Exterior Walls	Steel Stud - Exterior Infill Wall	Non Load Bearing	178	3.6	39 x 92	Plywood	20	15	37.5	2	Aluminum

#### 2- Details of Building Roofs

Sr. No.	Assembly	No. of Bays per Row	No. of Rows	Bay Size	Span	Concrete	Live Load	Floor Area
				(m)	(m)	Mpa	kPa	(m <sup>2</sup> )
1	First Floor Slab	2	3	9.15	9.1	30	2.4	500

### Appendix S3

#### Absolute Values - Energy – Total and primary energy consumed for Steel Building

		PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS	
Energy Source	Unit	Manufacturing	Transport	Total	Construction- Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
Hydro	MJ	1.77E+04	3.81E+01	<b>1.77E+04</b>	4.37E+02	1.33E+02	<b>5.70E+02</b>	8.90E+03	1.49E+00	1.70E+05	<b>1.79E+05</b>	1.38E+03	1.86E+01	<b>1.39E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.98E+05</b>	<b>1.98E+05</b>
Non-Hydro Renewable	MJ	5.51E+03	0.00E+00	<b>5.51E+03</b>	2.11E+02	0.00E+00	<b>2.11E+02</b>	9.18E+02	0.00E+00	1.21E+05	<b>1.22E+05</b>	9.42E+02	0.00E+00	<b>9.42E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.29E+05</b>	<b>1.29E+05</b>
Coal	MJ	1.23E+06	5.56E+02	<b>1.23E+06</b>	9.33E+03	1.94E+03	<b>1.13E+04</b>	2.42E+04	2.17E+01	2.52E+06	<b>2.54E+06</b>	2.04E+04	2.72E+02	<b>2.06E+04</b>	5.65E+04	0.00E+00	<b>5.65E+04</b>	<b>3.80E+06</b>	<b>3.86E+06</b>
Diesel	MJ	2.27E+04	6.41E+04	<b>8.67E+04</b>	5.49E+04	2.41E+05	<b>2.96E+05</b>	4.33E+03	2.73E+03	1.33E+06	<b>1.33E+06</b>	1.27E+05	3.08E+04	<b>1.57E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.87E+06</b>	<b>1.87E+06</b>
Gasoline	MJ	2.28E+01	0.00E+00	<b>2.28E+01</b>	3.56E+01	0.00E+00	<b>3.56E+01</b>	3.65E-01	0.00E+00	0.00E+00	<b>3.65E-01</b>	3.35E+03	0.00E+00	<b>3.35E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.41E+03</b>	<b>3.41E+03</b>
Heavy Fuel Oil	MJ	3.34E+05	6.20E+03	<b>3.40E+05</b>	1.39E+04	1.29E+04	<b>2.68E+04</b>	2.02E+03	1.47E+02	3.49E+04	<b>3.71E+04</b>	2.83E+03	1.80E+03	<b>4.63E+03</b>	-2.08E+03	0.00E+00	<b>-2.08E+03</b>	<b>4.09E+05</b>	<b>4.07E+05</b>
LPG	MJ	1.32E+03	8.32E+01	<b>1.40E+03</b>	1.16E+02	2.90E+02	<b>4.06E+02</b>	4.68E+01	3.25E+00	4.40E+03	<b>4.45E+03</b>	1.50E+02	4.06E+01	<b>1.90E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.45E+03</b>	<b>6.45E+03</b>
Natural Gas	MJ	8.71E+05	3.40E+03	<b>8.75E+05</b>	2.17E+04	1.18E+04	<b>3.35E+04</b>	5.90E+04	1.33E+02	2.36E+06	<b>2.42E+06</b>	2.31E+04	1.66E+03	<b>2.48E+04</b>	-9.57E+03	0.00E+00	<b>-9.57E+03</b>	<b>3.35E+06</b>	<b>3.34E+06</b>
Nuclear	MJ	1.16E+06	1.41E+02	<b>1.16E+06</b>	1.77E+04	4.90E+02	<b>1.82E+04</b>	3.13E+05	5.49E+00	8.38E+05	<b>1.15E+06</b>	6.72E+03	6.85E+01	<b>6.79E+03</b>	-2.25E+04	0.00E+00	<b>-2.25E+04</b>	<b>2.33E+06</b>	<b>2.31E+06</b>
Wood	MJ	7.57E+04	0.00E+00	<b>7.57E+04</b>	3.41E+03	0.00E+00	<b>3.41E+03</b>	7.47E+03	0.00E+00	0.00E+00	<b>7.47E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.66E+04</b>	<b>8.66E+04</b>
Total Primary Energy Consumption	MJ	3.72E+06	7.45E+04	<b>3.79E+06</b>	1.22E+05	2.69E+05	<b>3.90E+05</b>	4.20E+05	3.04E+03	7.37E+06	<b>7.79E+06</b>	1.86E+05	3.46E+04	<b>2.20E+05</b>	2.24E+04	0.00E+00	<b>2.24E+04</b>	<b>1.22E+07</b>	<b>1.22E+07</b>

## Appendix S4

### Absolute Values - Air Emissions for Steel Building

Emission	Unit	PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS	
		Manufacturing	Transport	Total	Construction-Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
1,4-Butanediol	g	8.89E-08	0.00E+00	8.89E-08	0.00E+00	0.00E+00	0.00E+00	8.89E-08	0.00E+00	0.00E+00	8.89E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-07	1.78E-07
1-Butanol	g	1.03E-08	0.00E+00	1.03E-08	0.00E+00	0.00E+00	0.00E+00	1.03E-08	0.00E+00	0.00E+00	1.03E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.07E-08	2.07E-08
1-Pentanol	g	2.85E-07	0.00E+00	2.85E-07	0.00E+00	0.00E+00	0.00E+00	2.85E-07	0.00E+00	0.00E+00	2.85E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.70E-07	5.70E-07
1-Pentene	g	2.15E-07	0.00E+00	2.15E-07	0.00E+00	0.00E+00	0.00E+00	2.15E-07	0.00E+00	0.00E+00	2.15E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.31E-07	4.31E-07
1-Propanol	g	2.13E-06	0.00E+00	2.13E-06	0.00E+00	0.00E+00	0.00E+00	2.13E-06	0.00E+00	0.00E+00	2.13E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.27E-06	4.27E-06
2-Butanone, 3,3-dimethyl-	g	2.24E+00	0.00E+00	2.24E+00	1.12E-01	0.00E+00	1.12E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.35E+00	2.35E+00
2-Butene, 2-methyl-	g	4.78E-11	0.00E+00	4.78E-11	0.00E+00	0.00E+00	0.00E+00	4.78E-11	0.00E+00	0.00E+00	4.78E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.56E-11	9.56E-11
2-Chloroacetophenone	g	4.08E-02	0.00E+00	4.08E-02	2.03E-03	0.00E+00	2.03E-03	2.68E-04	0.00E+00	5.47E-07	2.68E-04	7.87E-09	0.00E+00	7.87E-09	0.00E+00	0.00E+00	0.00E+00	4.31E-02	4.31E-02
2-Methyl-1-propanol	g	4.99E-07	0.00E+00	4.99E-07	0.00E+00	0.00E+00	0.00E+00	4.99E-07	0.00E+00	0.00E+00	4.99E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.99E-07	9.99E-07
2-Propanol	g	5.34E-04	0.00E+00	5.34E-04	0.00E+00	0.00E+00	0.00E+00	5.34E-04	0.00E+00	0.00E+00	5.34E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E-03	1.07E-03
5-methyl Chrysene	g	1.83E-04	0.00E+00	1.83E-04	8.43E-06	0.00E+00	8.43E-06	1.10E-05	0.00E+00	1.15E-03	1.16E-03	9.01E-06	0.00E+00	9.01E-06	0.00E+00	0.00E+00	0.00E+00	1.37E-03	1.37E-03
Acenaphthene	g	4.24E-03	0.00E+00	4.24E-03	1.95E-04	0.00E+00	1.95E-04	2.55E-04	0.00E+00	2.67E-02	2.70E-02	2.09E-04	0.00E+00	2.09E-04	0.00E+00	0.00E+00	0.00E+00	3.16E-02	3.16E-02
Acenaphthylene	g	2.08E-03	0.00E+00	2.08E-03	9.57E-05	0.00E+00	9.57E-05	1.25E-04	0.00E+00	1.31E-02	1.32E-02	1.02E-04	0.00E+00	1.02E-04	0.00E+00	0.00E+00	0.00E+00	1.55E-02	1.55E-02
Acetaldehyde	g	8.83E+01	0.00E+00	8.83E+01	2.21E+01	0.00E+00	2.21E+01	1.22E-01	0.00E+00	4.45E-05	1.22E-01	3.58E+01	0.00E+00	3.58E+01	0.00E+00	0.00E+00	0.00E+00	1.46E+02	1.46E+02
Acetic acid	g	1.83E+01	0.00E+00	1.83E+01	0.00E+00	0.00E+00	0.00E+00	1.83E+01	0.00E+00	0.00E+00	1.83E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.66E+01	3.66E+01
Acetone	g	6.99E+01	0.00E+00	6.99E+01	3.49E+00	0.00E+00	3.49E+00	5.11E-03	0.00E+00	0.00E+00	5.11E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.34E+01	7.34E+01
Acetophenone	g	8.75E-02	0.00E+00	8.75E-02	4.35E-03	0.00E+00	4.35E-03	5.73E-04	0.00E+00	1.17E-06	5.75E-04	1.69E-08	0.00E+00	1.69E-08	0.00E+00	0.00E+00	0.00E+00	9.24E-02	9.24E-02
Acrolein	g	2.11E+03	0.00E+00	2.11E+03	1.07E+02	0.00E+00	1.07E+02	1.30E+01	0.00E+00	1.52E+01	2.82E+01	4.43E+00	0.00E+00	4.43E+00	0.00E+00	0.00E+00	0.00E+00	2.25E+03	2.25E+03
Acrylic acid	g	1.38E-06	0.00E+00	1.38E-06	0.00E+00	0.00E+00	0.00E+00	1.38E-06	0.00E+00	0.00E+00	1.38E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-06	2.77E-06
Aldehydes	g	7.22E+00	0.00E+00	7.22E+00	1.37E-01	0.00E+00	1.37E-01	4.48E+00	0.00E+00	7.80E-01	5.26E+00	6.09E-03	0.00E+00	6.09E-03	0.00E+00	0.00E+00	0.00E+00	1.26E+01	1.26E+01
alpha-Pinene	g	1.05E+03	0.00E+00	1.05E+03	5.27E+01	0.00E+00	5.27E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E+03	1.11E+03
Ammonia	g	3.14E+02	1.04E+02	4.19E+02	2.79E+01	3.63E+02	3.91E+02	2.64E+02	4.06E+00	6.75E+02	9.44E+02	6.01E+01	5.13E+01	1.11E+02	0.00E+00	0.00E+00	0.00E+00	1.86E+03	1.86E+03
Ammonium chloride	g	8.70E+01	0.00E+00	8.70E+01	3.73E-01	0.00E+00	3.73E-01	7.90E+01	0.00E+00	2.12E+02	2.91E+02	1.66E+00	0.00E+00	1.66E+00	0.00E+00	0.00E+00	0.00E+00	3.80E+02	3.80E+02
Anthracene	g	1.75E-03	0.00E+00	1.75E-03	8.04E-05	0.00E+00	8.04E-05	1.05E-04	0.00E+00	1.10E-02	1.11E-02	8.60E-05	0.00E+00	8.60E-05	0.00E+00	0.00E+00	0.00E+00	1.30E-02	1.30E-02
Antimony	g	4.21E-01	0.00E+00	4.21E-01	1.92E-02	0.00E+00	1.92E-02	3.45E-02	0.00E+00	9.44E-01	9.78E-01	7.38E-03	0.00E+00	7.38E-03	0.00E+00	0.00E+00	0.00E+00	1.43E+00	1.43E+00
Arsenic	g	3.93E+00	0.00E+00	3.93E+00	1.79E-01	0.00E+00	1.79E-01	2.92E-01	0.00E+00	2.43E+01	2.45E+01	2.03E-01	0.00E+00	2.03E-01	0.00E+00	0.00E+00	0.00E+00	2.89E+01	2.89E+01
Benzene	g	8.13E+02	0.00E+00	8.13E+02	6.11E+01	0.00E+00	6.11E+01	2.19E+01	0.00E+00	7.02E+01	9.21E+01	4.41E+01	0.00E+00	4.41E+01	0.00E+00	0.00E+00	0.00E+00	1.01E+03	1.01E+03
Benzene, 1,2-dichloro-	g	5.41E-07	0.00E+00	5.41E-07	0.00E+00	0.00E+00	0.00E+00	5.41E-07	0.00E+00	0.00E+00	5.41E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-06	1.08E-06
Benzene, chloro-	g	1.28E-01	0.00E+00	1.28E-01	6.37E-03	0.00E+00	6.37E-03	8.41E-04	0.00E+00	1.72E-06	8.43E-04	2.47E-08	0.00E+00	2.47E-08	0.00E+00	0.00E+00	0.00E+00	1.36E-01	1.36E-01
Benzene, ethyl-	g	7.21E-01	0.00E+00	7.21E-01	2.73E-02	0.00E+00	2.73E-02	1.75E-01	0.00E+00	7.34E-06	1.75E-01	1.06E-07	0.00E+00	1.06E-07	0.00E+00	0.00E+00	0.00E+00	9.23E-01	9.23E-01
Benzo(a)anthracene	g	6.66E-04	0.00E+00	6.66E-04	3.06E-05	0.00E+00	3.06E-05	4.01E-05	0.00E+00	4.20E-03	4.24E-03	3.28E-05	0.00E+00	3.28E-05	0.00E+00	0.00E+00	0.00E+00	4.96E-03	4.96E-03
Benzo(a)pyrene	g	6.02E+00	0.00E+00	6.02E+00	1.46E-05	0.00E+00	1.46E-05	6.02E+00	0.00E+00	1.99E-03	6.02E+00	1.56E-05	0.00E+00	1.56E-05	0.00E+00	0.00E+00	0.00E+00	1.20E+01	1.20E+01
Benzo(b,j,k)fluoranthene	g	9.15E-04	0.00E+00	9.15E-04	4.21E-05	0.00E+00	4.21E-05	5.49E-05	0.00E+00	5.77E-03	5.82E-03	4.51E-05	0.00E+00	4.51E-05	0.00E+00	0.00E+00	0.00E+00	6.83E-03	6.83E-03
Benzo(ghi)perylene	g	2.25E-04	0.00E+00	2.25E-04	1.03E-05	0.00E+00	1.03E-05	1.36E-05	0.00E+00	1.42E-03	1.43E-03	1.11E-05	0.00E+00	1.11E-05	0.00E+00	0.00E+00	0.00E+00	1.68E-03	1.68E-03
Benzyl chloride	g	4.08E+00	0.00E+00	4.08E+00	2.03E-01	0.00E+00	2.03E-01	2.68E-02	0.00E+00	5.47E-05	2.68E-02	7.87E-07	0.00E+00	7.87E-07	0.00E+00	0.00E+00	0.00E+00	4.31E+00	4.31E+00
Beryllium	g	1.95E-01	0.00E+00	1.95E-01	9.02E-03	0.00E+00	9.02E-03	1.51E-02	0.00E+00	2.62E+00	2.64E+00	3.04E-02	0.00E+00	3.04E-02	0.00E+00	0.00E+00	0.00E+00	2.87E+00	2.87E+00
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methyl-	g	4.09E+02	0.00E+00	4.09E+02	2.04E+01	0.00E+00	2.04E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.29E+02	4.29E+02
Biphenyl	g	1.41E-02	0.00E+00	1.41E-02	6.51E-04	0.00E+00	6.51E-04	8.49E-04	0.00E+00	8.92E-02	9.00E-02	6.97E-04	0.00E+00	6.97E-04	0.00E+00	0.00E+00	0.00E+00	1.05E-01	1.05E-01
Bromoform	g	2.27E-01	0.00E+00	2.27E-01	1.13E-02	0.00E+00	1.13E-02	1.49E-03	0.00E+00	3.05E-06	1.49E-03	4.39E-08	0.00E+00	4.39E-08	0.00E+00	0.00E+00	0.00E+00	2.40E-01	2.40E-01
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene)	g	4.71E+01	0.00E+00	4.71E+01	1.42E+00	0.00E+00	1.42E+00	1.87E+01	0.00E+00	0.00E+00	1.87E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.72E+01	6.72E+01
Butadiene	g	6.30E-02	0.00E+00	6.30E-02	9.07E-01	0.00E+00	9.07E-01	4.09E-03	0.00E+00	0.00E+00	4.09E-03	1.82E+00	0.00E+00	1.82E+00	0.00E+00	0.00E+00	0.00E+00	2.80E+00	2.80E+00
Butane	g	9.19E+00	0.00E+00	9.19E+00	0.00E+00	0.00E+00	0.00E+00	9.19E+00	0.00E+00	0.00E+00	9.19E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.84E+01	1.84E+01
Butyrolactone	g	8.28E-09	0.00E+00	8.28E-09	0.00E+00	0.00E+00	0.00E+00	8.28E-09	0.00E+00	0.00E+00	8.28E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.66E-08	1.66E-08
Cadmium	g	3.33E+00	0.00E+00	3.33E+00	1.74E-02	0.00E+00	1.74E-02	7.52E-02	0.00E+00	5.37E+00	5.44E+00	5.21E-02	0.00E+00	5.21E-02	1.62E-01	0.00E+00	1.62E-01	8.84E+00	9.00E+00
Carbon dioxide, biogenic	kg	6.73E+03	0.00E+00	6.73E+03	3.04E+02	0.00E+00	3.04E+02	6.85E+02	0.00E+00	0.00E+00	6.85E+02	4.31E-03	0.00E+00	4.31E-03	0.00E+00	0.00E+00	0.00E+00	7.72E+03	7.72E+03

Carbon dioxide, biogenic, landfill	kg	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-1.35E+04	0.00E+00	<b>-1.35E+04</b>	<b>0.00E+00</b>	<b>-1.35E+04</b>
Carbon dioxide, fossil	kg	2.44E+05	5.65E+03	<b>2.49E+05</b>	8.90E+03	1.97E+04	<b>2.86E+04</b>	7.40E+03	2.21E+02	4.42E+05	<b>4.50E+05</b>	1.16E+04	2.76E+03	<b>1.44E+04</b>	4.53E+03	0.00E+00	<b>4.53E+03</b>	<b>7.43E+05</b>	<b>7.47E+05</b>
Carbon dioxide, land transformation	g	4.17E+05	0.00E+00	<b>4.17E+05</b>	1.03E+04	0.00E+00	<b>1.03E+04</b>	2.10E+05	0.00E+00	4.01E+06	<b>4.22E+06</b>	3.13E+04	0.00E+00	<b>3.13E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.68E+06</b>	<b>4.68E+06</b>
Carbon disulfide	g	7.90E-01	0.00E+00	<b>7.90E-01</b>	3.77E-02	0.00E+00	<b>3.77E-02</b>	3.68E-02	0.00E+00	1.02E-05	<b>3.68E-02</b>	1.46E-07	0.00E+00	<b>1.46E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.65E-01</b>	<b>8.65E-01</b>
Carbon monoxide	g	4.30E+05	9.09E+03	<b>4.39E+05</b>	-1.87E+04	3.78E+04	<b>1.91E+04</b>	5.24E+03	4.14E+02	6.34E+01	<b>5.72E+03</b>	9.16E-01	4.36E+03	<b>4.36E+03</b>	7.27E+04	0.00E+00	<b>7.27E+04</b>	<b>4.68E+05</b>	<b>5.41E+05</b>
Carbon monoxide, fossil	g	7.72E+04	2.02E+04	<b>9.74E+04</b>	3.91E+04	7.64E+04	<b>1.15E+05</b>	6.14E+03	8.51E+02	5.13E+05	<b>5.20E+05</b>	7.85E+04	9.63E+03	<b>8.81E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.21E+05</b>	<b>8.21E+05</b>
Chloride	g	1.64E+00	0.00E+00	<b>1.64E+00</b>	1.50E-08	0.00E+00	<b>1.50E-08</b>	1.64E+00	0.00E+00	0.00E+00	<b>1.64E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.28E+00</b>	<b>3.28E+00</b>
Chlorine	g	2.73E+01	0.00E+00	<b>2.73E+01</b>	1.23E+00	0.00E+00	<b>1.23E+00</b>	2.70E+00	0.00E+00	0.00E+00	<b>2.70E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.12E+01</b>	<b>3.12E+01</b>
Chloroform	g	3.44E-01	0.00E+00	<b>3.44E-01</b>	1.71E-02	0.00E+00	<b>1.71E-02</b>	2.27E-03	0.00E+00	4.61E-06	<b>2.27E-03</b>	6.64E-08	0.00E+00	<b>6.64E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.64E-01</b>	<b>3.64E-01</b>
Chromium	g	2.13E+01	0.00E+00	<b>2.13E+01</b>	4.78E-01	0.00E+00	<b>4.78E-01</b>	2.51E-01	0.00E+00	1.68E+01	<b>1.70E+01</b>	1.42E-01	0.00E+00	<b>1.42E-01</b>	-4.71E-01	0.00E+00	<b>-4.71E-01</b>	<b>3.90E+01</b>	<b>3.85E+01</b>
Chromium VI	g	6.57E-01	0.00E+00	<b>6.57E-01</b>	3.03E-02	0.00E+00	<b>3.03E-02</b>	3.96E-02	0.00E+00	4.14E+00	<b>4.18E+00</b>	3.24E-02	0.00E+00	<b>3.24E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.90E+00</b>	<b>4.90E+00</b>
Chrysene	g	8.32E-04	0.00E+00	<b>8.32E-04</b>	3.83E-05	0.00E+00	<b>3.83E-05</b>	5.03E-05	0.00E+00	5.24E-03	<b>5.29E-03</b>	4.10E-05	0.00E+00	<b>4.10E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.21E-03</b>	<b>6.21E-03</b>
Cobalt	g	2.35E+00	0.00E+00	<b>2.35E+00</b>	1.10E-01	0.00E+00	<b>1.10E-01</b>	1.28E-01	0.00E+00	7.91E+00	<b>8.04E+00</b>	6.49E-02	0.00E+00	<b>6.49E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.06E+01</b>	<b>1.06E+01</b>
Copper	g	8.49E-02	0.00E+00	<b>8.49E-02</b>	1.06E-03	0.00E+00	<b>1.06E-03</b>	7.26E-02	0.00E+00	3.00E+00	<b>3.07E+00</b>	4.31E-02	0.00E+00	<b>4.31E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.20E+00</b>	<b>3.20E+00</b>
Cumene	g	1.56E+02	0.00E+00	<b>1.56E+02</b>	7.55E+00	0.00E+00	<b>7.55E+00</b>	4.62E+00	0.00E+00	4.14E-07	<b>4.62E+00</b>	5.96E-09	0.00E+00	<b>5.96E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.68E+02</b>	<b>1.68E+02</b>
Cyanide	g	1.46E+01	0.00E+00	<b>1.46E+01</b>	7.24E-01	0.00E+00	<b>7.24E-01</b>	1.27E-01	0.00E+00	1.95E-04	<b>1.27E-01</b>	3.08E-06	0.00E+00	<b>3.08E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.55E+01</b>	<b>1.55E+01</b>
D-limonene	g	1.18E+02	0.00E+00	<b>1.18E+02</b>	5.91E+00	0.00E+00	<b>5.91E+00</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.24E+02</b>	<b>1.24E+02</b>
Dimethyl ether	g	1.12E+00	0.00E+00	<b>1.12E+00</b>	5.46E-02	0.00E+00	<b>5.46E-02</b>	3.23E-02	0.00E+00	0.00E+00	<b>3.23E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.21E+00</b>	<b>1.21E+00</b>
Dinitrogen monoxide	g	4.49E+03	4.61E-01	<b>4.49E+03</b>	2.22E+02	2.12E-02	<b>2.22E+02</b>	4.72E+01	3.07E-02	2.10E+03	<b>2.15E+03</b>	1.70E+01	1.46E-02	<b>1.70E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.87E+03</b>	<b>6.87E+03</b>
Dioxins, unspecified	g	6.07E-03	0.00E+00	<b>6.07E-03</b>	1.80E-04	0.00E+00	<b>1.80E-04</b>	1.29E-06	0.00E+00	0.00E+00	<b>1.29E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-3.42E-05	0.00E+00	<b>-3.42E-05</b>	<b>6.25E-03</b>	<b>6.22E-03</b>
Dipropylthiocarbamic acid S-ethyl ester	g	7.12E-05	0.00E+00	<b>7.12E-05</b>	3.56E-06	0.00E+00	<b>3.56E-06</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.47E-05</b>	<b>7.47E-05</b>
Ethane	g	3.72E+01	0.00E+00	<b>3.72E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.72E+01	0.00E+00	0.00E+00	<b>3.72E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.44E+01</b>	<b>7.44E+01</b>
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	g	2.93E-02	0.00E+00	<b>2.93E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.93E-02	0.00E+00	0.00E+00	<b>2.93E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.86E-02</b>	<b>5.86E-02</b>
Ethane, 1,1,1-trichloro-, HCFC-140	g	1.17E-01	1.46E-04	<b>1.17E-01</b>	5.92E-03	5.55E-04	<b>6.48E-03</b>	7.86E-04	6.16E-06	2.84E-03	<b>3.63E-03</b>	2.76E-04	7.01E-05	<b>3.46E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.27E-01</b>	<b>1.27E-01</b>
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	g	6.56E-08	0.00E+00	<b>6.56E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.56E-08	0.00E+00	0.00E+00	<b>6.56E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.31E-07</b>	<b>1.31E-07</b>
Ethane, 1,1-difluoro-, HFC-152a	g	8.04E-07	0.00E+00	<b>8.04E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.04E-07	0.00E+00	0.00E+00	<b>8.04E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.61E-06</b>	<b>1.61E-06</b>
Ethane, 1,2-dibromo-	g	7.00E-03	0.00E+00	<b>7.00E-03</b>	3.48E-04	0.00E+00	<b>3.48E-04</b>	4.59E-05	0.00E+00	9.38E-08	<b>4.60E-05</b>	1.35E-09	0.00E+00	<b>1.35E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.39E-03</b>	<b>7.39E-03</b>
Ethane, 1,2-dichloro-	g	2.34E-01	0.00E+00	<b>2.34E-01</b>	1.16E-02	0.00E+00	<b>1.16E-02</b>	2.12E-03	0.00E+00	3.13E-06	<b>2.12E-03</b>	4.50E-08	0.00E+00	<b>4.50E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.48E-01</b>	<b>2.48E-01</b>
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	g	1.15E-04	0.00E+00	<b>1.15E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.15E-04	0.00E+00	0.00E+00	<b>1.15E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.31E-04</b>	<b>2.31E-04</b>
Ethane, chloro-	g	2.45E-01	0.00E+00	<b>2.45E-01</b>	1.22E-02	0.00E+00	<b>1.22E-02</b>	1.61E-03	0.00E+00	3.28E-06	<b>1.61E-03</b>	4.72E-08	0.00E+00	<b>4.72E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.59E-01</b>	<b>2.59E-01</b>
Ethane, hexafluoro-, HFC-116	g	1.24E-04	0.00E+00	<b>1.24E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.24E-04	0.00E+00	0.00E+00	<b>1.24E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.48E-04</b>	<b>2.48E-04</b>
Ethanol	g	6.54E-03	0.00E+00	<b>6.54E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.54E-03	0.00E+00	0.00E+00	<b>6.54E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.31E-02</b>	<b>1.31E-02</b>
Ethene	g	2.86E+00	0.00E+00	<b>2.86E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.86E+00	0.00E+00	0.00E+00	<b>2.86E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.73E+00</b>	<b>5.73E+00</b>
Ethene, chloro-	g	1.21E-04	0.00E+00	<b>1.21E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.21E-04	0.00E+00	0.00E+00	<b>1.21E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.42E-04</b>	<b>2.42E-04</b>
Ethene, tetrachloro-	g	3.74E-01	0.00E+00	<b>3.74E-01</b>	1.73E-02	0.00E+00	<b>1.73E-02</b>	2.22E-02	0.00E+00	2.56E+00	<b>2.58E+00</b>	2.19E-02	0.00E+00	<b>2.19E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.00E+00</b>	<b>3.00E+00</b>
Ethene, trichloro-	g	4.19E-05	0.00E+00	<b>4.19E-05</b>	7.04E-11	0.00E+00	<b>7.04E-11</b>	4.19E-05	0.00E+00	0.00E+00	<b>4.19E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.39E-05</b>	<b>8.39E-05</b>
Ethyl acetate	g	2.48E-03	0.00E+00	<b>2.48E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.48E-03	0.00E+00	0.00E+00	<b>2.48E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.96E-03</b>	<b>4.96E-03</b>
Ethylamine	g	2.57E-07	0.00E+00	<b>2.57E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.57E-07	0.00E+00	0.00E+00	<b>2.57E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.15E-07</b>	<b>5.15E-07</b>
Ethylene oxide	g	1.28E-04	0.00E+00	<b>1.28E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.28E-04	0.00E+00	0.00E+00	<b>1.28E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.55E-04</b>	<b>2.55E-04</b>
Ethyne	g	2.40E+00	0.00E+00	<b>2.40E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.40E+00	0.00E+00	0.00E+00	<b>2.40E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.81E+00</b>	<b>4.81E+00</b>
Fluoranthene	g	5.91E-03	0.00E+00	<b>5.91E-03</b>	2.72E-04	0.00E+00	<b>2.72E-04</b>	3.55E-04	0.00E+00	3.72E-02	<b>3.76E-02</b>	2.91E-04	0.00E+00	<b>2.91E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.41E-02</b>	<b>4.41E-02</b>
Fluorene	g	1.54E-02	0.00E+00	<b>1.54E-02</b>	3.49E-04	0.00E+00	<b>3.49E-04</b>	8.30E-03	0.00E+00	4.77E-02	<b>5.60E-02</b>	3.73E-04	0.00E+00	<b>3.73E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.22E-02</b>	<b>7.22E-02</b>
Fluoride	g	2.62E+02	0.00E+00	<b>2.62E+02</b>	1.29E+01	0.00E+00	<b>1.29E+01</b>	3.48E+00	0.00E+00	4.77E+00	<b>8.25E+00</b>	3.73E-02	0.00E+00	<b>3.73E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.83E+02</b>	<b>2.83E+02</b>
Formaldehyde	g	3.25E+02	0.00E+00	<b>3.25E+02</b>	4.26E+01	0.00E+00	<b>4.26E+01</b>	1.69E+											

Indeno(1,2,3-cd)pyrene	g	5.07E-04	0.00E+00	<b>5.07E-04</b>	2.34E-05	0.00E+00	<b>2.34E-05</b>	3.05E-05	0.00E+00	3.20E-03	<b>3.23E-03</b>	2.50E-05	0.00E+00	<b>2.50E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.79E-03	<b>3.79E-03</b>
Isophorone	g	3.38E+00	0.00E+00	<b>3.38E+00</b>	1.68E-01	0.00E+00	<b>1.68E-01</b>	2.22E-02	0.00E+00	4.53E-05	<b>2.22E-02</b>	6.52E-07	0.00E+00	<b>6.52E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.57E+00	<b>3.57E+00</b>
Isoprene	g	1.02E+01	0.00E+00	<b>1.02E+01</b>	4.91E-01	0.00E+00	<b>4.91E-01</b>	4.07E-01	0.00E+00	0.00E+00	<b>4.07E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.11E+01	<b>1.11E+01</b>
Isopropylamine	g	3.32E-09	0.00E+00	<b>3.32E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.32E-09	0.00E+00	0.00E+00	<b>3.32E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.63E-09	<b>6.63E-09</b>
Kerosene	g	4.17E+01	0.00E+00	<b>4.17E+01</b>	1.78E-01	0.00E+00	<b>1.78E-01</b>	3.78E+01	0.00E+00	1.02E+02	<b>1.40E+02</b>	7.94E-01	0.00E+00	<b>7.94E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.82E+02	<b>1.82E+02</b>
Lead	g	7.19E+01	0.00E+00	<b>7.19E+01</b>	-2.34E-01	0.00E+00	<b>-2.34E-01</b>	5.88E-01	0.00E+00	2.76E+01	<b>2.82E+01</b>	2.46E-01	0.00E+00	<b>2.46E-01</b>	5.83E+00	0.00E+00	<b>5.83E+00</b>	1.00E+02	<b>1.06E+02</b>
m-Xylene	g	8.28E-03	0.00E+00	<b>8.28E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.28E-03	0.00E+00	0.00E+00	<b>8.28E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.66E-02	<b>1.66E-02</b>
Magnesium	g	9.16E+01	0.00E+00	<b>9.16E+01</b>	4.21E+00	0.00E+00	<b>4.21E+00</b>	5.60E+00	0.00E+00	5.77E+02	<b>5.82E+02</b>	4.51E+00	0.00E+00	<b>4.51E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.83E+02	<b>6.83E+02</b>
Manganese	g	5.89E+01	0.00E+00	<b>5.89E+01</b>	2.67E+00	0.00E+00	<b>2.67E+00</b>	5.42E+00	0.00E+00	3.03E+01	<b>3.58E+01</b>	2.58E-01	0.00E+00	<b>2.58E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	9.76E+01	<b>9.76E+01</b>
Mercaptans, unspecified	g	1.27E+03	0.00E+00	<b>1.27E+03</b>	6.29E+01	0.00E+00	<b>6.29E+01</b>	8.30E+00	0.00E+00	1.70E-02	<b>8.31E+00</b>	2.44E-04	0.00E+00	<b>2.44E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.34E+03	<b>1.34E+03</b>
Mercury	g	1.89E+01	0.00E+00	<b>1.89E+01</b>	5.25E-01	0.00E+00	<b>5.25E-01</b>	1.85E-01	0.00E+00	6.14E+00	<b>6.33E+00</b>	5.79E-02	0.00E+00	<b>5.79E-02</b>	-3.16E-02	0.00E+00	<b>-3.16E-02</b>	2.58E+01	<b>2.58E+01</b>
Metals, unspecified	g	1.47E+03	0.00E+00	<b>1.47E+03</b>	6.65E+01	0.00E+00	<b>6.65E+01</b>	1.37E+02	0.00E+00	0.00E+00	<b>1.37E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.67E+03	<b>1.67E+03</b>
Methacrylic acid, methyl ester	g	1.17E-01	0.00E+00	<b>1.17E-01</b>	5.79E-03	0.00E+00	<b>5.79E-03</b>	7.64E-04	0.00E+00	1.56E-06	<b>7.66E-04</b>	2.25E-08	0.00E+00	<b>2.25E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.23E-01	<b>1.23E-01</b>
Methane	g	4.00E+05	7.72E+01	<b>4.00E+05</b>	3.95E+03	1.03E+03	<b>4.98E+03</b>	3.24E+04	1.05E+01	1.08E+06	<b>1.11E+06</b>	8.51E+03	2.31E+01	<b>8.53E+03</b>	1.38E+04	0.00E+00	<b>1.38E+04</b>	1.53E+06	<b>1.54E+06</b>
Methane, biogenic, landfill	g	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.47E+05	0.00E+00	<b>1.47E+05</b>	0.00E+00	<b>1.47E+05</b>
Methane, bromo-, Halon 1001	g	9.33E-01	0.00E+00	<b>9.33E-01</b>	4.64E-02	0.00E+00	<b>4.64E-02</b>	6.12E-03	0.00E+00	1.25E-05	<b>6.13E-03</b>	1.80E-07	0.00E+00	<b>1.80E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	9.86E-01	<b>9.86E-01</b>
Methane, bromochlorodifluoro-, Halon 1211	g	1.09E-02	0.00E+00	<b>1.09E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.09E-02	0.00E+00	0.00E+00	<b>1.09E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.17E-02	<b>2.17E-02</b>
Methane, bromotrifluoro-, Halon 1301	g	4.40E-03	0.00E+00	<b>4.40E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.40E-03	0.00E+00	0.00E+00	<b>4.40E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.80E-03	<b>8.80E-03</b>
Methane, chlorodifluoro-, HCFC-22	g	3.72E-02	0.00E+00	<b>3.72E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.72E-02	0.00E+00	0.00E+00	<b>3.72E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.44E-02	<b>7.44E-02</b>
Methane, dichloro-, HCC-30	g	1.35E+01	0.00E+00	<b>1.35E+01</b>	6.16E-01	0.00E+00	<b>6.16E-01</b>	1.12E+00	0.00E+00	3.33E+01	<b>3.44E+01</b>	3.68E-01	0.00E+00	<b>3.68E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.88E+01	<b>4.88E+01</b>
Methane, dichlorodifluoro-, CFC-12	g	2.99E-04	1.81E-04	<b>4.80E-04</b>	1.57E-04	6.86E-04	<b>8.43E-04</b>	6.45E-05	7.63E-06	3.51E-03	<b>3.58E-03</b>	3.41E-04	8.69E-05	<b>4.28E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	5.33E-03	<b>5.33E-03</b>
Methane, dichlorofluoro-, HCFC-21	g	4.39E-10	0.00E+00	<b>4.39E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.39E-10	0.00E+00	0.00E+00	<b>4.39E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.78E-10	<b>8.78E-10</b>
Methane, fossil	g	2.07E+04	5.60E+03	<b>2.63E+04</b>	5.48E+03	2.13E+04	<b>2.68E+04</b>	4.06E+03	2.36E+02	1.93E+05	<b>1.98E+05</b>	1.16E+04	2.69E+03	<b>1.43E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.65E+05	<b>2.65E+05</b>
Methane, monochloro-, R-40	g	3.09E+00	0.00E+00	<b>3.09E+00</b>	1.54E-01	0.00E+00	<b>1.54E-01</b>	2.03E-02	0.00E+00	4.14E-05	<b>2.03E-02</b>	5.96E-07	0.00E+00	<b>5.96E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.27E+00	<b>3.27E+00</b>
Methane, tetrachloro-, CFC-10	g	7.03E-03	1.83E-05	<b>7.05E-03</b>	1.29E-04	6.92E-05	<b>1.98E-04</b>	4.74E-03	7.71E-07	3.51E-04	<b>5.10E-03</b>	3.41E-05	8.73E-06	<b>4.28E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.24E-02	<b>1.24E-02</b>
Methane, tetrafluoro-, CFC-14	g	1.08E-03	0.00E+00	<b>1.08E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.08E-03	0.00E+00	0.00E+00	<b>1.08E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.15E-03	<b>2.15E-03</b>
Methane, trichlorofluoro-, CFC-11	g	7.12E-10	0.00E+00	<b>7.12E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.12E-10	0.00E+00	0.00E+00	<b>7.12E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.42E-09	<b>1.42E-09</b>
Methane, trifluoro-, HFC-23	g	1.40E-07	0.00E+00	<b>1.40E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.40E-07	0.00E+00	0.00E+00	<b>1.40E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.79E-07	<b>2.79E-07</b>
Methanol	g	1.73E+03	0.00E+00	<b>1.73E+03</b>	8.10E+01	0.00E+00	<b>8.10E+01</b>	1.11E+02	0.00E+00	0.00E+00	<b>1.11E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.92E+03	<b>1.92E+03</b>
Methyl acetate	g	8.55E-10	0.00E+00	<b>8.55E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.55E-10	0.00E+00	0.00E+00	<b>8.55E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.71E-09	<b>1.71E-09</b>
Methyl acrylate	g	1.57E-06	0.00E+00	<b>1.57E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.57E-06	0.00E+00	0.00E+00	<b>1.57E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.14E-06	<b>3.14E-06</b>
Methyl amine	g	4.07E-08	0.00E+00	<b>4.07E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.07E-08	0.00E+00	0.00E+00	<b>4.07E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.14E-08	<b>8.14E-08</b>
Methyl ethyl ketone	g	1.28E+01	0.00E+00	<b>1.28E+01</b>	6.38E-01	0.00E+00	<b>6.38E-01</b>	2.18E-02	0.00E+00	3.05E-05	<b>2.18E-02</b>	4.39E-07	0.00E+00	<b>4.39E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.34E+01	<b>1.34E+01</b>
Methyl formate	g	1.44E-07	0.00E+00	<b>1.44E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.44E-07	0.00E+00	0.00E+00	<b>1.44E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.88E-07	<b>2.88E-07</b>
Methyl lactate	g	2.90E-07	0.00E+00	<b>2.90E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.90E-07	0.00E+00	0.00E+00	<b>2.90E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	5.79E-07	<b>5.79E-07</b>
Methyl methacrylate	g	1.73E-07	0.00E+00	<b>1.73E-07</b>	9.90E-10	0.00E+00	<b>9.90E-10</b>	1.53E-07	0.00E+00	0.00E+00	<b>1.53E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.26E-07	<b>3.26E-07</b>
Monoethanolamine	g	8.10E-05	0.00E+00	<b>8.10E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.10E-05	0.00E+00	0.00E+00	<b>8.10E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.62E-04	<b>1.62E-04</b>
Naphthalene	g	3.75E+00	0.00E+00	<b>3.75E+00</b>	1.70E-01	0.00E+00	<b>1.70E-01</b>	3.42E-01	0.00E+00	1.73E+00	<b>2.08E+00</b>	1.42E-02	0.00E+00	<b>1.42E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.01E+00	<b>6.01E+00</b>
Nickel	g	2.21E+01	0.00E+00	<b>2.21E+01</b>	1.05E+00	0.00E+00	<b>1.05E+00</b>	1.08E+00	0.00E+00	5.44E+01	<b>5.55E+01</b>	4.78E-01	0.00E+00	<b>4.78E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.92E+01	<b>7.92E+01</b>
Nitrate	g	1.21E-03	0.00E+00	<b>1.21E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.21E-03	0.00E+00	0.00E+00	<b>1.21E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.42E-03	<b>2.42E-03</b>
Nitrobenzene	g	1.59E-06	0.00E+00	<b>1.59E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.59E-06	0.00E+00	0.00E+00	<b>1.59E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.18E-06	<b>3.18E-06</b>
Nitrogen dioxide	g	1.01E+03	3.16E+03	<b>4.16E+03</b>	-4.99E+00	1.30E+04	<b>1.30E+04</b>	8.14E+01	1.42E+02	1.51E+01	<b>2.39E+02</b>	2.18E-01	1.52E+03	<b>1.52E+03</b>	4.60E+01	0.00E+00	<b>4.60E+01</b>	1.89E+04	<b>1.89E+04</b>
Nitrogen oxides	g	6.08E+05	7.28E+04	<b>6.80E+05</b>	8.84E+04	2.77E+05	<b>3.66E+05</b>	2.43E+04	3.09E+03	5.26E+05	<b>5.53E+05</b>	1.54E+05	3.46E+04	<b>1.89E+05</b>	4.35E+03	0.00E+00	<b>4.35E+03</b>	1.79E+06	<b>1.79E+06</b>
Nitrous oxides	g	1.06E+03	5.95E+00	<b>1.07E+03</b>	5.78E+00	1.92E+01	<b>2.50E+01</b>	2.84E-01	2.17E-01	2.96E-02	<b>5.31E-01</b>	4.26E-04	2.97E+00	<b>2.97E+00</b>	1.69E+01	0.00E+00	<b>1.69E+01</b>	1.10E+03	<b>1.12E+03</b>
N																			

Phenol	g	2.68E+01	0.00E+00	<b>2.68E+01</b>	1.33E+00	0.00E+00	<b>1.33E+00</b>	1.20E-01	0.00E+00	1.25E-06	<b>1.20E-01</b>	1.80E-08	0.00E+00	<b>1.80E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.83E+01	2.83E+01
Phenols, unspecified	g	2.71E+00	0.00E+00	<b>2.71E+00</b>	1.26E-01	0.00E+00	<b>1.26E-01</b>	2.07E-01	0.00E+00	1.44E+01	<b>1.46E+01</b>	1.95E-01	0.00E+00	<b>1.95E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.77E+01	1.77E+01
Phosphate	g	3.95E-02	0.00E+00	<b>3.95E-02</b>	1.97E-03	0.00E+00	<b>1.97E-03</b>	2.89E-05	0.00E+00	0.00E+00	<b>2.89E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.15E-02	4.15E-02
Phosphorus	g	2.50E-02	0.00E+00	<b>2.50E-02</b>	8.14E-10	0.00E+00	<b>8.14E-10</b>	2.51E-02	0.00E+00	0.00E+00	<b>2.51E-02</b>	1.66E-08	0.00E+00	<b>1.66E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	5.01E-02	5.01E-02
Phthalate, dioctyl-	g	4.26E-01	0.00E+00	<b>4.26E-01</b>	2.12E-02	0.00E+00	<b>2.12E-02</b>	2.79E-03	0.00E+00	5.70E-06	<b>2.80E-03</b>	8.21E-08	0.00E+00	<b>8.21E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.50E-01	4.50E-01
Propanal	g	2.22E+00	0.00E+00	<b>2.22E+00</b>	1.10E-01	0.00E+00	<b>1.10E-01</b>	1.46E-02	0.00E+00	2.97E-05	<b>1.46E-02</b>	4.27E-07	0.00E+00	<b>4.27E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.34E+00	2.34E+00
Propane	g	1.79E+01	0.00E+00	<b>1.79E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.79E+01	0.00E+00	0.00E+00	<b>1.79E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.58E+01	3.58E+01
Propene	g	6.26E+01	0.00E+00	<b>6.26E+01</b>	6.26E+01	0.00E+00	<b>6.26E+01</b>	3.09E+00	0.00E+00	0.00E+00	<b>3.09E+00</b>	1.20E+02	0.00E+00	<b>1.20E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.49E+02	2.49E+02
Propionic acid	g	1.24E-03	0.00E+00	<b>1.24E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.24E-03	0.00E+00	0.00E+00	<b>1.24E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.48E-03	2.48E-03
Propylene oxide	g	1.87E-03	0.00E+00	<b>1.87E-03</b>	7.62E-05	0.00E+00	<b>7.62E-05</b>	3.46E-04	0.00E+00	0.00E+00	<b>3.46E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.29E-03	2.29E-03
Pyrene	g	2.74E-03	0.00E+00	<b>2.74E-03</b>	1.26E-04	0.00E+00	<b>1.26E-04</b>	1.65E-04	0.00E+00	1.73E-02	<b>1.75E-02</b>	1.35E-04	0.00E+00	<b>1.35E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.05E-02	2.05E-02
Radioactive species, unspecified	MBq	1.41E+02	0.00E+00	<b>1.41E+02</b>	5.29E+00	0.00E+00	<b>5.29E+00</b>	2.62E+01	0.00E+00	2.97E+03	<b>3.00E+03</b>	2.32E+01	0.00E+00	<b>2.32E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.17E+03	3.17E+03
Radionuclides (Including Radon)	g	2.33E+03	0.00E+00	<b>2.33E+03</b>	9.98E+00	0.00E+00	<b>9.98E+00</b>	2.11E+03	0.00E+00	5.69E+03	<b>7.80E+03</b>	4.44E+01	0.00E+00	<b>4.44E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.02E+04	1.02E+04
Selenium	g	1.11E+01	0.00E+00	<b>1.11E+01</b>	5.12E-01	0.00E+00	<b>5.12E-01</b>	6.70E-01	0.00E+00	7.60E+01	<b>7.67E+01</b>	6.43E-01	0.00E+00	<b>6.43E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	8.89E+01	8.89E+01
Styrene	g	1.46E-01	0.00E+00	<b>1.46E-01</b>	7.24E-03	0.00E+00	<b>7.24E-03</b>	9.89E-04	0.00E+00	1.95E-06	<b>9.91E-04</b>	2.81E-08	0.00E+00	<b>2.81E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.54E-01	1.54E-01
Sulfur dioxide	g	7.79E+05	8.82E+01	<b>7.79E+05</b>	1.91E+04	3.09E+02	<b>1.95E+04</b>	6.05E+04	3.45E+00	2.66E+06	<b>2.72E+06</b>	2.10E+04	4.35E+01	<b>2.10E+04</b>	5.75E+03	0.00E+00	<b>5.75E+03</b>	3.54E+06	3.55E+06
Sulfur hexafluoride	g	6.29E-04	0.00E+00	<b>6.29E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	6.29E-04	0.00E+00	0.00E+00	<b>6.29E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.26E-03	1.26E-03
Sulfur oxides	g	2.81E+04	3.55E+03	<b>3.17E+04</b>	4.87E+03	1.35E+04	<b>1.83E+04</b>	4.23E+03	1.50E+02	9.24E+04	<b>9.67E+04</b>	8.68E+03	1.70E+03	<b>1.04E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.57E+05	1.57E+05
Sulfur trioxide	g	1.28E-05	0.00E+00	<b>1.28E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.28E-05	0.00E+00	0.00E+00	<b>1.28E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.56E-05	2.56E-05
Sulfuric acid	g	2.90E-06	0.00E+00	<b>2.90E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.90E-06	0.00E+00	0.00E+00	<b>2.90E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	5.81E-06	5.81E-06
Sulfuric acid, dimethyl ester	g	2.80E-01	0.00E+00	<b>2.80E-01</b>	1.39E-02	0.00E+00	<b>1.39E-02</b>	1.85E-03	0.00E+00	3.75E-06	<b>1.85E-03</b>	5.40E-08	0.00E+00	<b>5.40E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.96E-01	2.96E-01
t-Butyl methyl ether	g	2.04E-01	0.00E+00	<b>2.04E-01</b>	1.01E-02	0.00E+00	<b>1.01E-02</b>	1.59E-03	0.00E+00	2.73E-06	<b>1.59E-03</b>	3.94E-08	0.00E+00	<b>3.94E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.16E-01	2.16E-01
Tar	g	3.51E-07	0.00E+00	<b>3.51E-07</b>	1.68E-08	0.00E+00	<b>1.68E-08</b>	1.40E-08	0.00E+00	0.00E+00	<b>1.40E-08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.82E-07	3.82E-07
Terpenes	g	2.53E-04	0.00E+00	<b>2.53E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.53E-04	0.00E+00	0.00E+00	<b>2.53E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	5.07E-04	5.07E-04
TOC, Total Organic Carbon	g	1.40E+02	0.00E+00	<b>1.40E+02</b>	6.36E+00	0.00E+00	<b>6.36E+00</b>	1.31E+01	0.00E+00	0.00E+00	<b>1.31E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.60E+02	1.60E+02
Toluene	g	3.17E+00	0.00E+00	<b>3.17E+00</b>	9.55E+00	0.00E+00	<b>9.55E+00</b>	1.16E+00	0.00E+00	1.88E-05	<b>1.16E+00</b>	1.91E+01	0.00E+00	<b>1.91E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.30E+01	3.30E+01
Toluene, 2,4-dinitro-	g	1.63E-03	0.00E+00	<b>1.63E-03</b>	8.11E-05	0.00E+00	<b>8.11E-05</b>	1.07E-05	0.00E+00	2.19E-08	<b>1.07E-05</b>	3.15E-10	0.00E+00	<b>3.15E-10</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.73E-03	1.73E-03
Toluene, 2-chloro-	g	4.76E-07	0.00E+00	<b>4.76E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.76E-07	0.00E+00	0.00E+00	<b>4.76E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	9.52E-07	9.52E-07
Trimethylamine	g	1.52E-09	0.00E+00	<b>1.52E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.52E-09	0.00E+00	0.00E+00	<b>1.52E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	3.04E-09	3.04E-09
Vinyl acetate	g	4.43E-02	0.00E+00	<b>4.43E-02</b>	2.20E-03	0.00E+00	<b>2.20E-03</b>	2.91E-04	0.00E+00	5.94E-07	<b>2.91E-04</b>	8.55E-09	0.00E+00	<b>8.55E-09</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.68E-02	4.68E-02
VOC, volatile organic compounds	g	1.31E+04	1.91E+03	<b>1.50E+04</b>	2.40E+03	9.86E+03	<b>1.23E+04</b>	1.82E+03	1.06E+02	4.15E+04	<b>4.34E+04</b>	4.15E+03	8.59E+02	<b>5.00E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	7.56E+04	7.56E+04
Xylene	g	1.36E+00	0.00E+00	<b>1.36E+00</b>	6.62E+00	0.00E+00	<b>6.62E+00</b>	7.12E-01	0.00E+00	2.89E-06	<b>7.12E-01</b>	1.33E+01	0.00E+00	<b>1.33E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.20E+01	2.20E+01
Zinc	g	1.29E-01	0.00E+00	<b>1.29E-01</b>	2.54E-03	0.00E+00	<b>2.54E-03</b>	8.43E-02	0.00E+00	2.00E+00	<b>2.08E+00</b>	2.88E-02	0.00E+00	<b>2.88E-02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.24E+00	2.24E+00

## Appendix S5

### Absolute Values - Water Emissions for Steel Building

Emission	Unit	PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS		
		Manufacturing	Transport	Total	Construction-Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D	
2-Hexanone	mg	2.39E+02	4.53E+01	2.85E+02	3.86E+01	1.58E+02	1.97E+02	3.89E+01	1.77E+00	1.94E+03	1.98E+03	7.80E+01	2.21E+01	1.00E+02	0.00E+00	0.00E+00	0.00E+00	2.56E+03	2.56E+03	
Acetone	mg	3.67E+02	6.94E+01	4.36E+02	5.91E+01	2.42E+02	3.01E+02	5.96E+01	2.71E+00	2.96E+03	3.03E+03	1.19E+02	3.39E+01	1.53E+02	0.00E+00	0.00E+00	0.00E+00	3.92E+03	3.92E+03	
Acids, unspecified	mg	1.04E+03	0.00E+00	1.04E+03	4.13E+00	0.00E+00	4.13E+00	9.61E+02	0.00E+00	0.00E+00	9.61E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.01E+03	2.01E+03	
Aluminum	mg	1.76E+06	6.23E+05	2.38E+06	4.71E+05	2.17E+06	2.64E+06	2.89E+05	2.43E+04	1.31E+07	1.34E+07	9.64E+05	3.04E+05	1.27E+06	0.00E+00	0.00E+00	0.00E+00	1.97E+07	1.97E+07	
Ammonia	mg	2.64E+06	1.32E+05	2.77E+06	1.27E+05	4.61E+05	5.89E+05	7.95E+04	5.17E+03	4.38E+06	4.46E+06	2.17E+05	6.46E+04	2.82E+05	7.48E+03	0.00E+00	0.00E+00	7.48E+03	8.10E+06	8.11E+06
Ammonia, as N	mg	3.29E-03	0.00E+00	3.29E-03	1.58E-04	0.00E+00	1.58E-04	1.31E-04	0.00E+00	0.00E+00	1.31E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.58E-03	3.58E-03	
Ammonium, ion	mg	1.26E+05	0.00E+00	1.26E+05	2.58E+03	0.00E+00	2.58E+03	1.07E+06	0.00E+00	0.00E+00	1.07E+06	1.16E+02	0.00E+00	1.16E+02	0.00E+00	0.00E+00	0.00E+00	1.20E+06	1.20E+06	
Antimony	mg	1.06E+03	3.89E+02	1.45E+03	2.93E+02	1.36E+03	1.65E+03	1.52E+02	1.52E+01	8.14E+03	8.31E+03	6.02E+02	1.90E+02	7.92E+02	0.00E+00	0.00E+00	0.00E+00	1.22E+04	1.22E+04	
Arsenic, ion	mg	8.98E+03	1.92E+03	1.09E+04	1.59E+03	6.70E+03	8.29E+03	2.47E+03	7.51E+01	7.15E+04	7.40E+04	3.22E+03	9.38E+02	4.16E+03	0.00E+00	0.00E+00	0.00E+00	9.74E+04	9.74E+04	
Barium	mg	2.30E+07	8.52E+06	3.16E+07	6.46E+06	2.97E+07	3.62E+07	2.51E+06	3.33E+05	1.86E+08	1.89E+08	1.32E+07	4.16E+06	1.74E+07	0.00E+00	0.00E+00	0.00E+00	2.74E+08	2.74E+08	
Benzene	mg	3.17E+05	1.16E+04	3.28E+05	2.23E+04	4.06E+04	6.29E+04	1.77E+04	4.55E+02	4.97E+05	5.15E+05	2.00E+04	5.69E+03	2.57E+04	0.00E+00	0.00E+00	0.00E+00	9.32E+05	9.32E+05	
Benzene, 1-methyl-4-(1-methylethyl)-	µg	3.66E+03	6.94E+02	4.36E+03	5.91E+02	2.42E+03	3.01E+03	5.96E+02	2.71E+01	2.96E+04	3.02E+04	1.19E+03	3.39E+02	1.53E+03	0.00E+00	0.00E+00	0.00E+00	3.91E+04	3.91E+04	
Benzene, ethyl-	mg	3.66E+03	6.55E+02	4.31E+03	5.58E+02	2.28E+03	2.84E+03	7.59E+02	2.56E+01	2.80E+04	2.88E+04	1.13E+03	3.20E+02	1.45E+03	0.00E+00	0.00E+00	0.00E+00	3.74E+04	3.74E+04	
Benzene, pentamethyl-	µg	2.75E+03	5.20E+02	3.27E+03	4.43E+02	1.81E+03	2.26E+03	4.47E+02	2.03E+01	2.22E+04	2.27E+04	8.95E+02	2.54E+02	1.15E+03	0.00E+00	0.00E+00	0.00E+00	2.94E+04	2.94E+04	
Benzenes, alkylated, unspecified	mg	8.85E+02	3.41E+02	1.23E+03	2.57E+02	1.19E+03	1.45E+03	9.21E+01	1.33E+01	7.14E+03	7.24E+03	5.28E+02	1.67E+02	6.95E+02	0.00E+00	0.00E+00	0.00E+00	1.06E+04	1.06E+04	
Benzoic acid	mg	3.72E+04	7.04E+03	4.42E+04	6.00E+03	2.46E+04	3.06E+04	6.05E+03	2.75E+02	3.01E+05	3.07E+05	1.21E+04	3.44E+03	1.56E+04	0.00E+00	0.00E+00	0.00E+00	3.97E+05	3.97E+05	
Beryllium	mg	4.44E+02	1.08E+02	5.52E+02	8.71E+01	3.76E+02	4.63E+02	6.81E+01	4.21E+00	3.56E+03	3.63E+03	1.77E+02	5.26E+01	2.30E+02	0.00E+00	0.00E+00	0.00E+00	4.88E+03	4.88E+03	
Biphenyl	µg	5.73E+04	2.21E+04	7.94E+04	1.67E+04	7.70E+04	9.37E+04	5.96E+03	8.64E+02	4.62E+05	4.69E+05	3.42E+04	1.08E+04	4.50E+04	0.00E+00	0.00E+00	0.00E+00	6.87E+05	6.87E+05	
BOD5, Biological Oxygen Demand	mg	7.46E+07	1.27E+06	7.58E+07	4.04E+06	4.44E+06	8.48E+06	7.38E+07	4.98E+04	5.26E+07	1.26E+08	2.18E+06	6.22E+05	2.81E+06	3.51E+04	0.00E+00	0.00E+00	3.51E+04	2.14E+08	2.14E+08
Boron	mg	1.15E+05	2.18E+04	1.37E+05	1.86E+04	7.60E+04	9.45E+04	2.41E+04	8.52E+02	9.30E+05	9.55E+05	3.75E+04	1.06E+04	4.81E+04	0.00E+00	0.00E+00	0.00E+00	1.23E+06	1.23E+06	
Bromide	mg	7.86E+06	1.49E+06	9.35E+06	1.27E+06	5.19E+06	6.45E+06	1.28E+06	5.81E+04	6.35E+07	6.48E+07	2.56E+06	7.26E+05	3.29E+06	0.00E+00	0.00E+00	0.00E+00	8.39E+07	8.39E+07	
Cadmium, ion	mg	6.79E+03	2.84E+02	7.07E+03	2.72E+02	9.89E+02	1.26E+03	7.17E+02	1.11E+01	1.05E+04	1.12E+04	4.75E+02	1.38E+02	6.13E+02	6.16E+01	0.00E+00	0.00E+00	6.16E+01	2.01E+04	2.02E+04
Calcium, ion	mg	1.30E+08	2.23E+07	1.52E+08	1.90E+07	7.78E+07	9.68E+07	3.13E+07	8.72E+05	9.52E+08	9.84E+08	3.84E+07	1.09E+07	4.93E+07	0.00E+00	0.00E+00	0.00E+00	1.28E+09	1.28E+09	
Chloride	mg	1.42E+09	2.51E+08	1.67E+09	2.15E+08	8.74E+08	1.09E+09	2.75E+08	9.80E+06	1.07E+10	1.10E+10	4.31E+08	1.22E+08	5.54E+08	0.00E+00	0.00E+00	0.00E+00	1.43E+10	1.43E+10	
Chromium	mg	7.38E+04	1.66E+04	9.04E+04	1.26E+04	5.79E+04	7.05E+04	2.03E+03	6.49E+02	2.57E+05	2.60E+05	2.50E+04	8.11E+03	3.31E+04	-1.12E+02	0.00E+00	-1.12E+02	4.54E+05	4.54E+05	
Chromium VI	µg	5.27E+05	6.99E+04	5.97E+05	5.10E+04	2.44E+05	2.95E+05	4.09E+05	2.73E+03	1.08E+06	1.49E+06	1.05E+05	3.41E+04	1.39E+05	0.00E+00	0.00E+00	0.00E+00	2.52E+06	2.52E+06	
Chromium, ion	mg	1.39E+04	1.08E+03	1.50E+04	1.21E+03	3.75E+03	4.97E+03	2.74E+03	4.21E+01	1.12E+05	1.15E+05	2.38E+03	5.26E+02	2.91E+03	0.00E+00	0.00E+00	0.00E+00	1.38E+05	1.38E+05	
Cobalt	mg	1.08E+03	1.54E+02	1.23E+03	1.31E+02	5.36E+02	6.67E+02	6.11E+02	6.01E+00	6.57E+03	7.18E+03	2.65E+02	7.51E+01	3.40E+02	0.00E+00	0.00E+00	0.00E+00	9.42E+03	9.42E+03	
COD, Chemical Oxygen Demand	mg	6.09E+07	2.43E+06	6.33E+07	2.66E+06	8.48E+06	1.11E+07	2.77E+08	9.51E+04	9.20E+07	3.69E+08	4.12E+06	1.19E+06	5.31E+06	-2.48E+04	0.00E+00	-2.48E+04	4.49E+08	4.49E+08	
Copper, ion	mg	9.62E+03	2.00E+03	1.16E+04	1.58E+03	6.97E+03	8.55E+03	1.35E+04	7.81E+01	5.87E+04	7.23E+04	3.23E+03	9.76E+02	4.21E+03	0.00E+00	0.00E+00	0.00E+00	9.67E+04	9.67E+04	
Cyanide	mg	2.01E+04	5.01E-01	2.01E+04	7.27E+02	1.75E+00	7.28E+02	5.60E+03	1.96E-02	2.14E+01	5.62E+03	8.62E-01	2.45E-01	1.11E+00	0.00E+00	0.00E+00	0.00E+00	2.65E+04	2.65E+04	
Decane	mg	1.07E+03	2.02E+02	1.27E+03	1.72E+02	7.06E+02	8.78E+02	1.74E+02	7.91E+00	8.64E+03	8.82E+03	3.48E+02	9.88E+01	4.47E+02	0.00E+00	0.00E+00	0.00E+00	1.14E+04	1.14E+04	
Detergent, oil	mg	3.44E+04	5.78E+03	4.01E+04	5.06E+03	2.02E+04	2.52E+04	5.80E+03	2.26E+02	2.78E+05	2.84E+05	1.02E+04	2.82E+03	1.30E+04	0.00E+00	0.00E+00	0.00E+00	3.62E+05	3.62E+05	
Dibenzofuran	µg	6.97E+03	1.32E+03	8.29E+03	1.12E+03	4.60E+03	5.73E+03	1.13E+03	5.16E+01	5.64E+04	5.75E+04	2.27E+03	6.45E+02	2.92E+03	0.00E+00	0.00E+00	0.00E+00	7.45E+04	7.45E+04	
Dibenzothiophene	µg	3.82E+03	6.82E+01	3.89E+03	1.82E+02	2.38E+02	4.19E+02	8.52E+02	2.67E+00	3.02E+04	3.10E+04	3.34E+02	3.33E+01	3.67E+02	0.00E+00	0.00E+00	0.00E+00	3.57E+04	3.57E+04	
Dissolved solids	mg	1.58E+09	3.09E+08	1.89E+09	2.62E+08	1.08E+09	1.34E+09	2.39E+08	1.21E+07	1.32E+10	1.35E+10	5.32E+08	1.51E+08	6.83E+08	2.03E+04	0.00E+00	2.03E+04	1.74E+10	1.74E+10	
DOC, Dissolved Organic Carbon	mg	2.06E+06	0.00E+00	2.06E+06	7.33E+04	0.00E+00	7.33E+04	2.49E+08	0.00E+00	0.00E+00	2.49E+08	2.88E+04	0.00E+00	2.88E+04	0.00E+00	0.00E+00	0.00E+00	2.51E+08	2.51E+08	
Docosane	µg	3.92E+04	7.43E+03	4.67E+04	6.33E+03	2.59E+04	3.22E+04	6.38E+03	2.90E+02	3.17E+05	3.24E+05	1.28E+04	3.63E+03	1.64E+04	0.00E+00	0.00E+00	0.00E+00	4.19E+05	4.19E+05	
Dodecane	mg	2.03E+03	3.84E+02	2.41E+03	3.27E+02	1.34E+03	1.67E+03	3.30E+02	1.50E+01	1.64E+04	1.67E+04	6.60E+02	1.88E+02	8.48E+02	0.00E+00	0.00E+00	0.00E+00	2.17E+04	2.17E+04	
Eicosane	mg	5.58E+02	1.06E+02	6.64E+02	9.00E+01	3.69E+02	4.59E+02	9.08E+01	4.13E+00	4.51E+03	4.61E+03	1.82E+02	5.16E+01	2.33E+02	0.00E+00	0.00E+00	0.00E+00	5.96E+03	5.96E+03	
Fluorene, 1-methyl-	µg	4.17E+03	7.90E+02	4.96E+03	6.73E+02	2.76E+03	3.43E+03	6.79E+02	3.09E+01	3.37E+04	3.44E+04	1.36E+03	3.86E+02	1.74E+03	0.00E+00	0.00E+00	0.00E+00	4.46E+04	4.46E+04	
Fluorenes, alkylated, unspecified	µg	5.13E+04	1.98E+04	7.11E+04	1.49E+04	6.90E+04	8.39E+04	5.34E+03	7.73E+02	4.14E+05	4.20E+05	3.06E+04	9.66E+03	4.03E+04	0.00E+00	0.00E+00	0.00E+00	6.15E+05	6.15E+05	
Fluoride	mg	3.38E+05	0.00E+00	3.38E+05	1.40E+04	0.00E+00	1.40E+04	1.11E+05	0.00E+00	0.00E+00	1.11E+05	6.00E+00	0.00E+00	6.00E+00	0.00E+00	0.00E+00	0.00E+00	4.63E+05	4.63E+05	
Fluorine	µg	2.69E+04	9.74E+03	3.66E+04	7.40E+03	3.39E+04	4.13E+04	3.00E+03	3.81E+02	2.17E+05	2.20E+05	1.52E+04	4.75E+03	1.99E+04	0.00E+00	0.00E+00	0.00E+00	3.18E+05	3.18E+05	
Hexadecane	mg	2.21E+03	4.19E+02	2.63E+03	3.57E+02	1.46E+03	1.82E+03	3.60E+02	1.64E+01	1.79E+04	1.83E+04	7.21E+02	2.05E+02	9.26E+02	0.00E+00	0.00E+00	0.00E+00	2.36E+04	2.36E+04	

Hexanoic acid	mg	7.70E+03	1.46E+03	<b>9.16E+03</b>	1.24E+03	5.09E+03	<b>6.33E+03</b>	1.25E+03	5.70E+01	6.23E+04	<b>6.36E+04</b>	2.51E+03	7.12E+02	<b>3.22E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.23E+04</b>	<b>8.23E+04</b>
Hydrocarbons, unspecified	µg	5.66E+06	0.00E+00	<b>5.66E+06</b>	4.69E+03	0.00E+00	<b>4.69E+03</b>	5.57E+06	0.00E+00	0.00E+00	<b>5.57E+06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.12E+07</b>	<b>1.12E+07</b>
Hydrogen sulfide	mg	6.44E+01	0.00E+00	<b>6.44E+01</b>	1.27E-01	0.00E+00	<b>1.27E-01</b>	2.24E+04	0.00E+00	0.00E+00	<b>2.24E+04</b>	2.59E+00	0.00E+00	<b>2.59E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.25E+04</b>	<b>2.25E+04</b>
Iron	mg	3.99E+07	1.23E+06	<b>4.11E+07</b>	1.43E+06	4.30E+06	<b>5.72E+06</b>	5.59E+05	4.82E+04	3.09E+07	<b>3.15E+07</b>	1.95E+06	6.02E+05	<b>2.55E+06</b>	-2.42E+05	0.00E+00	<b>-2.42E+05</b>	<b>8.09E+07</b>	<b>8.07E+07</b>
Lead	mg	3.22E+04	4.09E+03	<b>3.63E+04</b>	3.50E+03	1.42E+04	<b>1.77E+04</b>	7.42E+04	1.60E+02	1.23E+05	<b>1.98E+05</b>	6.63E+03	1.99E+03	<b>8.62E+03</b>	-3.23E+02	0.00E+00	<b>-3.23E+02</b>	<b>2.60E+05</b>	<b>2.60E+05</b>
Lead-210/kg	µg	8.48E+07	7.21E-04	<b>8.48E+07</b>	6.14E-04	2.51E-03	<b>3.13E-03</b>	8.48E+07	2.82E-05	3.08E-02	<b>8.48E+07</b>	1.24E-03	3.52E-04	<b>1.59E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.70E+08</b>	<b>1.70E+08</b>
Lithium, ion	mg	2.51E+07	7.45E+03	<b>2.51E+07</b>	9.11E+05	2.60E+04	<b>9.37E+05</b>	5.49E+06	2.91E+02	2.03E+08	<b>2.08E+08</b>	1.62E+06	3.64E+03	<b>1.63E+06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.36E+08</b>	<b>2.36E+08</b>
m-Xylene	mg	1.11E+03	2.10E+02	<b>1.32E+03</b>	1.79E+02	7.33E+02	<b>9.13E+02</b>	1.81E+02	8.22E+00	8.98E+03	<b>9.17E+03</b>	3.62E+02	1.03E+02	<b>4.65E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.19E+04</b>	<b>1.19E+04</b>
Magnesium	mg	2.31E+07	4.36E+06	<b>2.74E+07</b>	3.71E+06	1.52E+07	<b>1.89E+07</b>	4.26E+06	1.70E+05	1.86E+08	<b>1.91E+08</b>	7.50E+06	2.13E+06	<b>9.63E+06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.47E+08</b>	<b>2.47E+08</b>
Manganese	mg	1.59E+06	6.95E+03	<b>1.60E+06</b>	1.03E+04	2.42E+04	<b>3.46E+04</b>	1.60E+06	2.72E+02	8.95E+05	<b>2.49E+06</b>	1.66E+04	3.39E+03	<b>2.00E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.15E+06</b>	<b>4.15E+06</b>
Mercury	µg	2.02E+04	6.82E+03	<b>2.70E+04</b>	5.20E+03	2.38E+04	<b>2.90E+04</b>	7.89E+05	2.67E+02	1.43E+05	<b>9.32E+05</b>	1.06E+04	3.33E+03	<b>1.40E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.00E+06</b>	<b>1.00E+06</b>
Metallic ions, unspecified	mg	1.23E+05	0.00E+00	<b>1.23E+05</b>	2.98E+03	0.00E+00	<b>2.98E+03</b>	6.33E+04	0.00E+00	0.00E+00	<b>6.33E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.89E+05</b>	<b>1.89E+05</b>
Methane, monochloro-, R-40	µg	1.48E+03	2.79E+02	<b>1.76E+03</b>	2.38E+02	9.74E+02	<b>1.21E+03</b>	2.40E+02	1.09E+01	1.19E+04	<b>1.22E+04</b>	4.81E+02	1.36E+02	<b>6.17E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.58E+04</b>	<b>1.58E+04</b>
Methyl ethyl ketone	µg	2.95E+03	5.59E+02	<b>3.51E+03</b>	4.76E+02	1.95E+03	<b>2.42E+03</b>	4.80E+02	2.18E+01	2.39E+04	<b>2.44E+04</b>	9.61E+02	2.73E+02	<b>1.23E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.15E+04</b>	<b>3.15E+04</b>
Molybdenum	mg	8.79E+02	1.60E+02	<b>1.04E+03</b>	1.36E+02	5.57E+02	<b>6.92E+02</b>	9.83E+02	6.24E+00	6.81E+03	<b>7.80E+03</b>	2.75E+02	7.79E+01	<b>3.53E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>9.89E+03</b>	<b>9.89E+03</b>
n-Hexacosane	µg	2.45E+04	4.64E+03	<b>2.91E+04</b>	3.95E+03	1.62E+04	<b>2.01E+04</b>	3.98E+03	1.81E+02	1.98E+05	<b>2.02E+05</b>	7.97E+03	2.26E+03	<b>1.02E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.61E+05</b>	<b>2.61E+05</b>
Naphthalene	mg	6.62E+02	1.27E+02	<b>7.88E+02</b>	1.08E+02	4.41E+02	<b>5.49E+02</b>	1.03E+02	4.95E+00	5.39E+03	<b>5.50E+03</b>	2.18E+02	6.18E+01	<b>2.79E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.11E+03</b>	<b>7.11E+03</b>
Naphthalene, 2-methyl-	mg	5.81E+02	1.10E+02	<b>6.91E+02</b>	9.36E+01	3.83E+02	<b>4.77E+02</b>	9.45E+01	4.30E+00	4.69E+03	<b>4.79E+03</b>	1.89E+02	5.37E+01	<b>2.43E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.20E+03</b>	<b>6.20E+03</b>
Naphthalenes, alkylated, unspecified	µg	1.45E+04	5.59E+03	<b>2.01E+04</b>	4.22E+03	1.95E+04	<b>2.37E+04</b>	1.51E+03	2.19E+02	1.17E+05	<b>1.19E+05</b>	8.65E+03	2.73E+03	<b>1.14E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.74E+05</b>	<b>1.74E+05</b>
Nickel	mg	1.90E+04	1.91E+03	<b>2.09E+04</b>	1.59E+03	6.66E+03	<b>8.25E+03</b>	2.91E+03	7.46E+01	6.26E+04	<b>6.56E+04</b>	3.13E+03	9.32E+02	<b>4.07E+03</b>	1.96E+02	0.00E+00	<b>1.96E+02</b>	<b>9.88E+04</b>	<b>9.90E+04</b>
Nitrate	mg	3.95E+05	0.00E+00	<b>3.95E+05</b>	1.60E+04	0.00E+00	<b>1.60E+04</b>	3.35E+05	0.00E+00	0.00E+00	<b>3.35E+05</b>	3.03E+01	0.00E+00	<b>3.03E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.46E+05</b>	<b>7.46E+05</b>
Nitrate compounds	mg	8.88E-05	0.00E+00	<b>8.88E-05</b>	4.26E-06	0.00E+00	<b>4.26E-06</b>	3.54E-06	0.00E+00	0.00E+00	<b>3.54E-06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>9.66E-05</b>	<b>9.66E-05</b>
Nitric acid	mg	1.99E-01	0.00E+00	<b>1.99E-01</b>	9.57E-03	0.00E+00	<b>9.57E-03</b>	7.93E-03	0.00E+00	0.00E+00	<b>7.93E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.17E-01</b>	<b>2.17E-01</b>
Nitrogen	mg	2.08E+06	0.00E+00	<b>2.08E+06</b>	-1.07E+05	0.00E+00	<b>-1.07E+05</b>	1.59E+06	0.00E+00	0.00E+00	<b>1.59E+06</b>	1.81E+02	0.00E+00	<b>1.81E+02</b>	3.92E+05	0.00E+00	<b>3.92E+05</b>	<b>3.56E+06</b>	<b>3.96E+06</b>
o-Cresol	mg	1.05E+03	2.00E+02	<b>1.25E+03</b>	1.70E+02	6.96E+02	<b>8.66E+02</b>	1.72E+02	7.81E+00	8.53E+03	<b>8.70E+03</b>	3.44E+02	9.75E+01	<b>4.41E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.13E+04</b>	<b>1.13E+04</b>
Octadecane	mg	5.47E+02	1.04E+02	<b>6.50E+02</b>	8.82E+01	3.61E+02	<b>4.49E+02</b>	8.89E+01	4.05E+00	4.42E+03	<b>4.51E+03</b>	1.78E+02	5.06E+01	<b>2.29E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.84E+03</b>	<b>5.84E+03</b>
Oils, unspecified	mg	2.35E+06	1.61E+05	<b>2.51E+06</b>	1.70E+05	5.63E+05	<b>7.33E+05</b>	9.81E+05	6.31E+03	6.35E+06	<b>7.34E+06</b>	2.73E+05	7.88E+04	<b>3.52E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.09E+07</b>	<b>1.09E+07</b>
Other	mg	2.31E+07	0.00E+00	<b>2.31E+07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.31E+07	0.00E+00	0.00E+00	<b>2.31E+07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>4.62E+07</b>	<b>4.62E+07</b>
Other metals	mg	2.87E+06	0.00E+00	<b>2.87E+06</b>	1.21E+02	0.00E+00	<b>1.21E+02</b>	2.86E+06	0.00E+00	0.00E+00	<b>2.86E+06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.73E+06</b>	<b>5.73E+06</b>
p-Cresol	mg	1.14E+03	2.16E+02	<b>1.35E+03</b>	1.83E+02	7.51E+02	<b>9.35E+02</b>	1.85E+02	8.42E+00	9.20E+03	<b>9.39E+03</b>	3.71E+02	1.05E+02	<b>4.76E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.22E+04</b>	<b>1.22E+04</b>
PAH, polycyclic aromatic hydrocarbons	µg	4.69E+04	0.00E+00	<b>4.69E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.69E+04	0.00E+00	0.00E+00	<b>4.69E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>9.39E+04</b>	<b>9.39E+04</b>
Pentanone, methyl-	mg	1.49E+02	2.92E+01	<b>1.78E+02</b>	2.47E+01	1.02E+02	<b>1.26E+02</b>	2.25E+01	1.14E+00	1.25E+03	<b>1.27E+03</b>	5.02E+01	1.43E+01	<b>6.44E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.64E+03</b>	<b>1.64E+03</b>
Phenanthrene	µg	6.80E+03	1.98E+03	<b>8.78E+03</b>	1.55E+03	6.91E+03	<b>8.46E+03</b>	8.98E+02	7.74E+01	5.49E+04	<b>5.58E+04</b>	3.17E+03	9.67E+02	<b>4.14E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.72E+04</b>	<b>7.72E+04</b>
Phenanthrenes, alkylated, unspecified	µg	6.01E+03	2.32E+03	<b>8.33E+03</b>	1.75E+03	8.09E+03	<b>9.83E+03</b>	6.26E+02	9.06E+01	4.85E+04	<b>4.92E+04</b>	3.59E+03	1.13E+03	<b>4.72E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.21E+04</b>	<b>7.21E+04</b>
Phenol	µg	1.38E+07	3.09E+06	<b>1.69E+07</b>	2.60E+06	1.08E+07	<b>1.34E+07</b>	1.31E+06	1.21E+05	4.79E+07	<b>4.93E+07</b>	4.65E+06	1.51E+06	<b>6.16E+06</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>8.57E+07</b>	<b>8.57E+07</b>
Phenol, 2,4-dimethyl-	mg	1.03E+03	1.94E+02	<b>1.22E+03</b>	1.66E+02	6.78E+02	<b>8.44E+02</b>	1.67E+02	7.60E+00	8.30E+03	<b>8.48E+03</b>	3.34E+02	9.50E+01	<b>4.29E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.10E+04</b>	<b>1.10E+04</b>
Phenols, unspecified	mg	1.13E+04	4.35E+02	<b>1.18E+04</b>	6.95E+02	1.51E+03	<b>2.21E+03</b>	2.40E+03	1.70E+01	9.12E+04	<b>9.37E+04</b>	1.32E+03	2.12E+02	<b>1.54E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.09E+05</b>	<b>1.09E+05</b>
Phosphate	mg	2.18E+05	0.00E+00	<b>2.18E+05</b>	8.85E+03	0.00E+00	<b>8.85E+03</b>	2.33E+04	0.00E+00	0.00E+00	<b>2.33E+04</b>	6.73E-01	0.00E+00	<b>6.73E-01</b>	-5.65E+02	0.00E+00	<b>-5.65E+02</b>	<b>2.50E+05</b>	<b>2.49E+05</b>
Phosphorus	mg	2.04E+04	0.00E+00	<b>2.04E+04</b>	7.16E+02	0.00E+00	<b>7.16E+02</b>	6.18E+03	0.00E+00	0.00E+00	<b>6.18E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-1.71E+03	0.00E+00	<b>-1.71E+03</b>	<b>2.73E+04</b>	<b>2.56E+04</b>
Radioactive species, Nuclides, unspecified	mg	8.94E+08	0.00E+00	<b>8.94E+08</b>	3.58E+07	0.00E+00	<b>3.58E+07</b>	1.79E+08	0.00E+00	0.00E+00	<b>1.79E+08</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.11E+09</b>	<b>1.11E+09</b>
Radium-226/kg	µg	1.32E+00	2.51E-01	<b>1.57E+00</b>	2.14E-01	8.75E-01	<b>1.09E+00</b>	2.08E-01	9.81E-03	1.07E+01	<b>1.09E+01</b>	4.32E-01	1.23E-01	<b>5.54E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.41E+01</b>	<b>1.41E+01</b>
Radium-228/kg	µg	6.74E-03	1.28E-03	<b>8.02E-03</b>	1.09E-03	4.47E-03	<b>5.56E-03</b>	1.06E-03	5.01E-05	5.48E-02	<b>5.59E-02</b>	2.21E-03	6.26E-04	<b>2.83E-03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.23E-02</b>	<b>7.23E-02</b>
Selenium	µg	2.20E+05	7.54E+04	<b>2.95E+05</b>	5.70E+04	2.63E+05	<b>3.20E+05</b>	4.19E+04	2.95E+03	1.59E+06	<b>1.63E+06</b>	1.17E+05	3.68E+04	<b>1.54E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.40E+06</b>	<b>2.40E+06</b>
Silver	mg	7.69E+04	1.46E+04	<b>9.15E+04</b>	1.24E+04	5.09E+04	<b>6.33E+04</b>	1.25E+04	5.70E+02	6.22E+05	<b>6.35E+05</b>	2.51E+04	7.12E+03	<b>3.22E+0</b>					

Tetradecane	mg	8.89E+02	1.68E+02	<b>1.06E+03</b>	1.43E+02	5.87E+02	<b>7.30E+02</b>	1.45E+02	6.58E+00	7.18E+03	<b>7.33E+03</b>	2.89E+02	8.22E+01	<b>3.72E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>9.49E+03</b>	<b>9.49E+03</b>
Thallium	µg	2.19E+05	8.20E+04	<b>3.01E+05</b>	6.18E+04	2.86E+05	<b>3.48E+05</b>	2.78E+04	3.20E+03	1.72E+06	<b>1.75E+06</b>	1.27E+05	4.00E+04	<b>1.67E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.56E+06</b>	<b>2.56E+06</b>
Tin	mg	5.65E+03	1.56E+03	<b>7.21E+03</b>	1.23E+03	5.44E+03	<b>6.68E+03</b>	8.37E+02	6.10E+01	4.50E+04	<b>4.59E+04</b>	2.51E+03	7.62E+02	<b>3.28E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.30E+04</b>	<b>6.30E+04</b>
Titanium, ion	mg	3.04E+04	5.97E+03	<b>3.63E+04</b>	4.51E+03	2.08E+04	<b>2.53E+04</b>	1.65E+04	2.34E+02	1.25E+05	<b>1.42E+05</b>	9.24E+03	2.92E+03	<b>1.22E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.16E+05</b>	<b>2.16E+05</b>
Toluene	mg	5.91E+04	1.10E+04	<b>7.01E+04</b>	9.37E+03	3.84E+04	<b>4.77E+04</b>	1.05E+04	4.30E+02	4.70E+05	<b>4.81E+05</b>	1.89E+04	5.37E+03	<b>2.43E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>6.23E+05</b>	<b>6.23E+05</b>
Vanadium	mg	1.53E+03	1.89E+02	<b>1.72E+03</b>	1.61E+02	6.57E+02	<b>8.18E+02</b>	6.93E+02	7.37E+00	8.05E+03	<b>8.75E+03</b>	3.24E+02	9.21E+01	<b>4.16E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.17E+04</b>	<b>1.17E+04</b>
Xylene	mg	1.29E+04	5.77E+03	<b>1.87E+04</b>	4.24E+03	2.01E+04	<b>2.43E+04</b>	1.86E+03	2.25E+02	9.34E+04	<b>9.55E+04</b>	8.70E+03	2.82E+03	<b>1.15E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.50E+05</b>	<b>1.50E+05</b>
Yttrium	mg	2.47E+02	4.68E+01	<b>2.94E+02</b>	3.98E+01	1.63E+02	<b>2.03E+02</b>	4.02E+01	1.83E+00	2.00E+03	<b>2.04E+03</b>	8.05E+01	2.29E+01	<b>1.03E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.64E+03</b>	<b>2.64E+03</b>
Zinc	mg	1.15E+05	1.43E+04	<b>1.30E+05</b>	1.26E+04	5.00E+04	<b>6.26E+04</b>	4.10E+04	5.61E+02	3.15E+05	<b>3.57E+05</b>	2.23E+04	7.00E+03	<b>2.93E+04</b>	-2.88E+03	0.00E+00	<b>-2.88E+03</b>	<b>5.78E+05</b>	<b>5.75E+05</b>

## Appendix S6

### Absolute Values - Land Emissions for Steel Building

		PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS	
Emission	Unit	Manufacturing	Transport	Total	Construction- Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
Bark/Wood Waste	kg	1.04E+03	0.00E+00	<b>1.04E+03</b>	1.54E+01	0.00E+00	<b>1.54E+01</b>	7.33E+02	0.00E+00	0.00E+00	<b>7.33E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.79E+03</b>	<b>1.79E+03</b>
Concrete Solid Waste	kg	1.41E+04	0.00E+00	<b>1.41E+04</b>	7.03E+02	0.00E+00	<b>7.03E+02</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.48E+04</b>	<b>1.48E+04</b>
Blast Furnace Dust	kg	7.40E+02	0.00E+00	<b>7.40E+02</b>	3.70E+01	0.00E+00	<b>3.70E+01</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.77E+02</b>	<b>7.77E+02</b>
Steel Waste	kg	1.73E+00	0.00E+00	<b>1.73E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.73E+00	0.00E+00	0.00E+00	<b>1.73E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.45E+00</b>	<b>3.45E+00</b>
Other Solid Waste	kg	5.99E+03	6.16E+01	<b>6.05E+03</b>	2.94E+02	2.15E+02	<b>5.09E+02</b>	8.04E+02	2.41E+00	3.10E+04	<b>3.18E+04</b>	3.27E+02	3.01E+01	<b>3.58E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.87E+04</b>	<b>3.87E+04</b>
Solid Waste to Landfill	kg	8.92E+01	0.00E+00	<b>8.92E+01</b>	1.40E+04	0.00E+00	<b>1.40E+04</b>	2.46E+03	0.00E+00	0.00E+00	<b>2.46E+03</b>	2.85E+05	0.00E+00	<b>2.85E+05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.02E+05</b>	<b>3.02E+05</b>

## Appendix S7

### Absolute Values - Ecologically Weighted Resource Use for Steel Building

		PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS	
Material	Unit	Manufacturing	Transport	Total	Construction- Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
Ash	kg	7.24E+02	0.00E+00	<b>7.24E+02</b>	3.62E+01	0.00E+00	<b>3.62E+01</b>	3.65E-05	0.00E+00	0.00E+00	<b>3.65E-05</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>7.60E+02</b>	<b>7.60E+02</b>
Carbon dioxide, in air	kg	2.94E+04	0.00E+00	<b>2.94E+04</b>	1.39E+03	0.00E+00	<b>1.39E+03</b>	2.57E-01	0.00E+00	0.00E+00	<b>2.57E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	2.02E+01	0.00E+00	<b>2.02E+01</b>	<b>3.08E+04</b>	<b>3.08E+04</b>
Clay & Shale	kg	3.27E+04	0.00E+00	<b>3.27E+04</b>	1.64E+03	0.00E+00	<b>1.64E+03</b>	2.08E+00	0.00E+00	0.00E+00	<b>2.08E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.44E+04</b>	<b>3.44E+04</b>
Coal	kg	5.72E+04	2.74E+01	<b>5.73E+04</b>	7.65E+02	9.54E+01	<b>8.61E+02</b>	1.18E+03	1.07E+00	1.21E+05	<b>1.22E+05</b>	9.83E+02	1.34E+01	<b>9.96E+02</b>	2.38E+03	0.00E+00	<b>2.38E+03</b>	<b>1.82E+05</b>	<b>1.84E+05</b>
Coarse Aggregate	kg	3.41E+05	0.00E+00	<b>3.41E+05</b>	1.70E+04	0.00E+00	<b>1.70E+04</b>	9.77E+02	0.00E+00	0.00E+00	<b>9.77E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.59E+05</b>	<b>3.59E+05</b>
Crude Oil	L	7.23E+03	1.68E+03	<b>8.91E+03</b>	1.69E+03	2.05E+03	<b>3.74E+03</b>	4.35E+02	2.93E+01	3.57E+04	<b>3.62E+04</b>	3.40E+03	8.53E+02	<b>4.25E+03</b>	-4.99E+01	0.00E+00	<b>-4.99E+01</b>	<b>5.31E+04</b>	<b>5.31E+04</b>
Dolomite	kg	7.22E+03	0.00E+00	<b>7.22E+03</b>	3.95E+01	0.00E+00	<b>3.95E+01</b>	9.57E-01	0.00E+00	0.00E+00	<b>9.57E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.16E+02	0.00E+00	<b>1.16E+02</b>	<b>7.26E+03</b>	<b>7.38E+03</b>
Ferrous scrap	kg	1.01E+05	0.00E+00	<b>1.01E+05</b>	1.10E+03	0.00E+00	<b>1.10E+03</b>	1.76E+01	0.00E+00	0.00E+00	<b>1.76E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.02E+05</b>	<b>1.02E+05</b>
Fine Aggregate	kg	2.29E+05	0.00E+00	<b>2.29E+05</b>	1.15E+04	0.00E+00	<b>1.15E+04</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.41E+05</b>	<b>2.41E+05</b>
Gypsum (Natural)	kg	5.08E+03	0.00E+00	<b>5.08E+03</b>	2.54E+02	0.00E+00	<b>2.54E+02</b>	1.41E-07	0.00E+00	0.00E+00	<b>1.41E-07</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>5.34E+03</b>	<b>5.34E+03</b>
Gypsum (Synthetic)	kg	1.76E-04	0.00E+00	<b>1.76E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	1.76E-04	0.00E+00	0.00E+00	<b>1.76E-04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.51E-04</b>	<b>3.51E-04</b>
Iron Ore	kg	2.81E+04	0.00E+00	<b>2.81E+04</b>	-1.18E+03	0.00E+00	<b>-1.18E+03</b>	1.15E+01	0.00E+00	0.00E+00	<b>1.15E+01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.55E+03	0.00E+00	<b>4.55E+03</b>	<b>2.69E+04</b>	<b>3.15E+04</b>
Lignite	kg	2.33E+03	0.00E+00	<b>2.33E+03</b>	7.67E+01	0.00E+00	<b>7.67E+01</b>	2.70E-01	0.00E+00	0.00E+00	<b>2.70E-01</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-1.59E+02	0.00E+00	<b>-1.59E+02</b>	<b>2.40E+03</b>	<b>2.24E+03</b>
Limestone	kg	1.21E+05	0.00E+00	<b>1.21E+05</b>	5.99E+03	0.00E+00	<b>5.99E+03</b>	1.86E+02	0.00E+00	0.00E+00	<b>1.86E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-1.78E+02	0.00E+00	<b>-1.78E+02</b>	<b>1.27E+05</b>	<b>1.27E+05</b>
Natural Gas	m3	2.31E+04	8.99E+01	<b>2.31E+04</b>	5.73E+02	3.14E+02	<b>8.86E+02</b>	1.86E+03	3.51E+00	6.27E+04	<b>6.45E+04</b>	6.13E+02	4.39E+01	<b>6.57E+02</b>	-2.46E+02	0.00E+00	<b>-2.46E+02</b>	<b>8.92E+04</b>	<b>8.90E+04</b>
Other	kg	1.14E+03	0.00E+00	<b>1.14E+03</b>	1.76E+00	0.00E+00	<b>1.76E+00</b>	1.10E+03	0.00E+00	0.00E+00	<b>1.10E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.24E+03</b>	<b>2.24E+03</b>
Sand	kg	1.85E+03	0.00E+00	<b>1.85E+03</b>	7.19E+01	0.00E+00	<b>7.19E+01</b>	4.08E+02	0.00E+00	0.00E+00	<b>4.08E+02</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>2.33E+03</b>	<b>2.33E+03</b>
Semi-Cementitious Material	kg	1.74E+04	0.00E+00	<b>1.74E+04</b>	8.68E+02	0.00E+00	<b>8.68E+02</b>	0.00E+00	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>1.82E+04</b>	<b>1.82E+04</b>
Tin ore	kg	8.45E-10	0.00E+00	<b>8.45E-10</b>	9.29E-12	0.00E+00	<b>9.29E-12</b>	1.41E-13	0.00E+00	0.00E+00	<b>1.41E-13</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	-2.83E-13	0.00E+00	<b>-2.83E-13</b>	<b>8.54E-10</b>	<b>8.54E-10</b>
Uranium	kg	9.01E-01	2.22E-04	<b>9.01E-01</b>	9.54E-03	7.75E-04	<b>1.03E-02</b>	4.95E-01	8.69E-06	1.33E+00	<b>1.82E+00</b>	1.06E-02	1.08E-04	<b>1.07E-02</b>	-9.83E-03	0.00E+00	<b>-9.83E-03</b>	<b>2.74E+00</b>	<b>2.73E+00</b>
Water	L	7.19E+06	0.00E+00	<b>7.19E+06</b>	2.78E+05	0.00E+00	<b>2.78E+05</b>	1.23E+04	0.00E+00	0.00E+00	<b>1.23E+04</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	4.20E+04	0.00E+00	<b>4.20E+04</b>	<b>7.48E+06</b>	<b>7.52E+06</b>
Wood Fiber	kg	2.89E+04	0.00E+00	<b>2.89E+04</b>	1.33E+03	0.00E+00	<b>1.33E+03</b>	2.25E+03	0.00E+00	0.00E+00	<b>2.25E+03</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	0.00E+00	0.00E+00	<b>0.00E+00</b>	<b>3.25E+04</b>	<b>3.25E+04</b>