Master’s Thesis

Impact of Construction Material on Environment

(Steel & Concrete)

Heera Lomite
Sridhar Kare

This Thesis is an obligatory part for the Master’s Program in Industrial Engineering with specialization in Quality & Environmental Management & provides 15 Credits
Nr. 1/2009
Impact of Construction Material on Environment

(Steel & Concrete)

Students:
Heera Lomite
Sridhar Kare

Master Thesis
Subject Category: Technology
Series and Number: Industrial Engineering: Quality & Environmental Management, 1/2009

University College of Borås
School of Engineering
SE 501 90 BORÅS
Telephone: +46 033 435 4640

Examiner: Mr. Roy Andersson
Supervisor: Dr. Maria Fredriksson
Date: March, 2009
Keywords: Impacts on Environment, Recycling, Reuse, Steel, Concrete, Material Selection, CO₂ emissions, Life Cycle Assessment.
Abstract

All around the globe the consumption of raw materials by the construction industries is accumulating day by day resulting with a depletion of natural resources, increasing the environmental impacts and CO\textsubscript{2} emissions all over the surroundings. Today steel and concrete are widely used and are dominating construction materials in construction industry. These two construction materials are different products and have distinct production flow with significant impact on the environment. The amount of embodied energy and operational energy which is consumed in the process of production, recycling and reuse are becoming increasingly more important in the construction industries due to the potential shortage of natural resources in the near by future and due to the inflation in the energy prices.

This master’s thesis determines some of the problems of antagonistic environmental impacts due to the use of steel and concrete in the construction industries. To mitigate these environmental impacts there are two technology and policy strategies summarized in this thesis.

i. Reduce consumption; and

ii. Material selection to reduce impacts.

i. **Reduce consumption:** All around the globe the consumption of materials is growing day by day with an increase in the population resulting with a depletion of virgin materials. This depletion of virgin materials can be reduced with the help of recycling and reuse of the structural members. Recycling of structural members is already practiced widely than reuse; reuse of the structural members additionally reduces the consumption of virgin materials. High level of reuse of the structural materials can be achieved by establishing design standards and regulations for structural sections, and developing a market for reusable structural sections.

ii. **Material selection to reduce impacts:** For the selection of construction materials with minimum impact on the environment the designers needs to have apropos education or tools. The main areas for augmentation are identified as education of designers, and standardization and simplification of selection tools like Life Cycle Assessment (LCA). Some of the main
recommendations are: LCA tools standardization; reduce the impact sections and make these impact sections comprehensible and integrate uncertainty data and educating designers about material selection tools with organized programs.
Acknowledgements

We would like to thank our parents for their unconditional support who put up with long hours and gave us push to complete our thesis.

Furthermore we would like to thank our instructor Dr. Maria Fredriksson who was an inspiration and continual source of knowledge, motivation and good conversation. We thank Mr. Henrik Eriksson for reading our thesis and offering valuable advice. We would also like to thank Mr. Roy Andersson for his valuable time. Thank You.

During our thesis we had much input and feedback from my close friends.

Finally, we would like to thank our colleague at University College of Boras for their views and opinions.

Heera Lomite
Sridhar Kare
9th March, 2009
### Abbreviations:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGC</td>
<td>Association of General Contractors</td>
</tr>
<tr>
<td>BEES</td>
<td>Building for Environmental &amp; Economic Sustainability</td>
</tr>
<tr>
<td>BOF</td>
<td>Blast Oxygen Furnace</td>
</tr>
<tr>
<td>Cement</td>
<td>A powdery product made from limestone and small amounts of other raw materials, heated to form clinker, which is then ground to a powder with small amounts of gypsum and other additives.</td>
</tr>
<tr>
<td>CFC-11</td>
<td>Trichlorofluoromethane</td>
</tr>
<tr>
<td>Concrete</td>
<td>A construction material made from a mixture of sand and rocks bound together with cement.</td>
</tr>
<tr>
<td>CPM</td>
<td>Centre for Environmental Assessment of Product &amp; Material System</td>
</tr>
<tr>
<td>C₂H₆</td>
<td>Ethane</td>
</tr>
<tr>
<td>DALY</td>
<td>Disability Adjusted Life Years</td>
</tr>
<tr>
<td>Dioxins</td>
<td>Informal term for the family of polychlorinated dibenzo dioxins and related polychlorinated dibenzo furans.</td>
</tr>
<tr>
<td>EAF</td>
<td>Electric Arc Furnace</td>
</tr>
<tr>
<td>ELU</td>
<td>Environmental Load Unit</td>
</tr>
<tr>
<td>EPS</td>
<td>Environmental Priorities Strategies</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>LCA</td>
<td>Life Cycle Assessment</td>
</tr>
<tr>
<td>LC₅₀</td>
<td>Lethal Concentration 50</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Nitrogen Oxide</td>
</tr>
<tr>
<td>OECD</td>
<td>Organization for Economic Cooperation &amp; Development countries</td>
</tr>
<tr>
<td>PO₄</td>
<td>Phosphate</td>
</tr>
<tr>
<td>TRACI</td>
<td>Tool for Reduction and Assessment of Chemical and other Environmental Impacts</td>
</tr>
<tr>
<td>MJ</td>
<td>Megajolues</td>
</tr>
</tbody>
</table>

Note that throughout this report, the unit “t” signifies metric tones; 1 tone = 1000 kilograms.
# TABLE OF CONTENTS

ABSTRACT ........................................................................................................... iii

ACKNOWLEDGEMENTS ..................................................................................... v

ABBREVIATIONS .............................................................................................. vi

TABLE OF CONTENTS ..................................................................................... vii

LIST OF FIGURES ........................................................................................... xi

LIST OF TABLES .............................................................................................. xii

1. INTRODUCTION ........................................................................................ 1

   1.1 Introduction .......................................................................................... 1
   1.2 Problem discussion ............................................................................. 1
   1.3 Purpose of this study .......................................................................... 2
       1.3.1 Theoretical objectives ................................................................. 3

2. METHODOLOGY .......................................................................................... 2

   2.1 Research Strategy .............................................................................. 4
   2.2 Scientific perspective ........................................................................ 4
       2.2.1 Positivistic paradigm ................................................................. 4
       2.2.2 Deductive approach ................................................................. 4
       2.2.3 Qualitative analysis ................................................................. 5

3. PROBLEM ASSESSMENT ............................................................................ 6

   3.1 Introduction ......................................................................................... 6
   3.2 Trends in consumption ...................................................................... 6
   3.3 Environmental Impacts and Embodied Energies .............................. 9
   3.4 Summary ............................................................................................. 10
4. RECYCLING AND REUSE

4.1 Introduction

4.2 Recycling and Reuse

4.2.1 Recycling

4.2.2 Reuse

4.3 Recycling and Reuse of Steel

4.3.1 Recycling of Steel

4.3.1.1 The amount of steel recycled in the construction industries

4.3.1.2 Composition of steel used in construction industry

4.3.1.2.1 Basic Oxygen Furnace (BOF)

4.3.1.2.2 Electric Arc Furnace (EAF)

4.3.2 Reuse of Steel

4.4 Recycling and Reuse of Concrete

4.4.1 Recycling of Concrete

4.4.2 Reuse of Concrete

4.5 Summary

5. MATERIAL SELECTION

5.1 Introduction

5.2 Designer’s Role

5.3 Tools for the Designers for selection of construction materials

5.3.1 BEES

5.3.2 ATHENA

5.4 Significance of LCA tools

5.5 Summary

6. LIFE CYCLE ASSESSMENT APPROACHES

6.1 Introduction

6.2 Four Main phases of LCA

6.2.1 Goal and Scope

6.2.1.1 Definition of functional unit

6.2.1.2 Product system and system boundaries

6.2.2 Life cycle inventory
6.2.2.1 Effects due to Time………………………………………………33
6.2.2.2 Effects due to Geographical……………………………………33
6.2.2.3 Effects due to Technology………………………………………34
6.2.2.4 Allocation procedures……………………………………………34
6.2.3 Life cycle impact assessment………………………………………..34
  6.2.3.1 Impact categories identification………………………………35
  6.2.3.2 Definition of impact indicator and impact indicator units……35
  6.2.3.3 Different Classification………………………………………35
  6.2.3.4 Impact characterization…………………………………………35
  6.2.3.5 Normalization and weighting……………………………………35
6.2.4 Interpretation……………………………………………………………36
6.3 Approaches for Impact Assessment……………………………………36
  6.3.1 TRACI - Impact Assessment Approach……………………………37
  6.3.2 The Environment Priority Strategies (EPS) system………………38
  6.3.3 The Eco-indicator system…………………………………………39
6.4 Summary …………………………………………………………………41

7. ANALYSIS………………………………………………………………….42
  7.1 Recycling………………………………………………………………43
  7.2 Reuse……………………………………………………………………43
  7.3 Energy Consumption…………………………………………………43
  7.4 CO₂ Emission…………………………………………………………..43
  7.5 Resource Depreciation…………………………………………………44
  7.6 Production………………………………………………………………44
  7.7 Landfill…………………………………………………………………44

8. CONCLUSION…………………………………………………………….45
  8.1 Overview………………………………………………………………45
  8.2 Problem Assessment…………………………………………………..45
    8.2.1 First Strategy: Reduce consumption……………………………..45
    8.2.2 Second Strategy: Material selection……………………………..46
  8.3 Final Conclusion………………………………………………………...46
9. REFERENCES ..................................................................................48
   9.1 Literature ...................................................................................48
   9.2 Internet Links .............................................................................48
List of figures

Figure 3-1: Trends of World and US. Steel and Cement consumption .......................... 6
Figure 3-2: World and U.S. CO2 emissions due to steel and cement consumption ........ 7
Figure 3-3 World per capita production of steel and cement ................................. 8
Figure 3-4: Projections of production ........................................................................ 9
Figure 3-5: Embodied energy of materials per unit weight ........................................ 9
Figure 3-6: Emission per unit weight of different structural construction materials ...... 10
Figure 4.1 Construction Structural, Recycling Rates (in Percent) ............................ 14
Figure 4.2 Construction Reinforcement, Recycling Rates (In Percent) .................... 14
Figure 4.3 Overall Steel Recycling Rates (in Percent) ........................................... 15
Figure 4.4: Blast Furnace ....................................................................................... 17
Figure 4.5: Electric Arc Furnace ............................................................................ 19
Figure 4.6: Steel recycling ..................................................................................... 20
Figure 4.7: Comparison of energy and CO2 emissions per ton of virgin steel, recycled steel and concrete ................................................................. 20
Figure 4.8: Building collapse due to soft-story mechanism in the 2003 Boumerdes earthquake (WHE Report 103, Algeria) ...................................................... 22
Figure 6-1: Life Cycle of a Product ......................................................................... 30
Figure 6-2 Development of an LCA inventory ....................................................... 31
Figure 6.3: Phases of life cycle assessment ............................................................. 32
Figure 6-4: Graphical representation of TRACI ................................................... 37
Figure 6-5: The Eco-indicator weighting triangle ................................................. 40
List of tables

Table 4.1 Total primary energy consumption and CO₂ emission (global average, Blast furnace) ............................................................. 18

Table 4.2 Total primary energy consumption and CO₂ emission (global average, Electric Arc furnace) ............................................................. 20

Table 6-1: Life Cycle Impact Categories in TRACI .......................................................... 38

Table 7-1: Analysis: Steel and Concrete .......................................................... 42
1. Introduction

The increase of unstable activities by human is resulting in some serious damages like tsunami, wildfires, flooding and drought due to global warming, rising of sea level, depletion of ozone layer causing increasing threats of cancer and land loss due to contamination of soil. Construction industries have a larger part in contributing these environmental problems. The extensive resource depletion is occurred due to the usage of large volumes of construction materials.

All round the world construction materials generate million tons of waste annually. These construction materials require high embodied energy resulting with large CO₂ (Carbon Dioxide) emissions. The embodied energy of steel is about 32 MJ/Kg and for cement is about 7.8 MJ/Kg (Scientific and Industrial Research Organization). The highest CO₂ producing material is cement and a large amount of CO₂ is produced in the processing of construction materials and in the transport of these materials. If the consumption of the construction materials remains the same all around the world then by the year 2050 the production of the cement in the world could reach 3.5 billion metric tons. But annually the production and consumption of the construction materials are increasing simultaneously, if this is the case then the production of cement itself annually could reach over 5 billion metric tons with approximately about 4 billion tons of CO₂ (carbon dioxide) emissions.

Due to the abundant usage of the construction materials the impact of these materials is dominated than from the impact of the other sources. Due to the frequent changes in the lifestyle and demands of human the average life of the buildings is decreasing, the demolition or renovation of the buildings are resulted with more land-fills or recycling annually. Because of the huge consumption of the construction materials and embodied energy a high level of resource depletion is taking place all around the world.

1.2 Problem discussion:
This thesis work gives an insight of the environmental hazards faced due to the consumption of uncontrolled construction materials. Although the achievement is to
reduce these impact but with the increase in consumption of construction materials these achievement looks unpromising. To appease these unfavorable environmental impacts is the more realistic ultimate goal.

Based on this the thesis problem statement is developed as to estimate the unfavorable environmental impacts caused due to consumption of construction materials and defining the important methods to alleviate these impacts.

By reducing the consumption of construction materials or by reducing the impacts caused by each construction material the unfavorable environmental impacts can be alleviated to some extent. This can be done in two methods to diminish the environmental hazards.

1. **Abate the consumption of construction materials:** The natural resources are gradually reducing with growing population and people’s demand. By recycling and reusing the construction materials will avoid the need for new resources and thus saving the natural resources or reducing the consumption of construction materials.

2. **Selection of construction materials:** Designer plays an important role in selection of the material. This can be done by the environmental performance of the material. To evaluate the judgment a tool should be available to the designer for selecting material to accomplish the goal of minimizing the environmental impacts.

**1.3 Purpose of this study:**

The purpose of this thesis work is to give an overview and to understand deeply the concept of “Impact of Construction Material (Steel & Concrete) on Environment” which is defined and interpreted in theory. In order to get an overview theoretical study is conducted which is carrying out by research work on relevant literature through textbooks, scientific articles, internet etc.
1.3.1. Theoretical objectives:

- Brief presentation and an overview of the concept of “Impact of Construction Material (Steel & Concrete) on Environment”.
- Emphasize the various impacts on environment and the methodology in the selection of materials based on their performance on environment.
- Reducing the consumption of materials by recycling and reuse by implementing latest technology and policy.
2. METHODOLOGY

2.1 Research Strategy
Mainly there are two types of approaches in writing thesis they are theoretical and empirical. In the theoretical approach, it requires an exclusive textual investigation and in the empirical approach, it requires a broad communication and interactions with people. This thesis mainly focuses on the theoretical approach and it is essential to have a good theoretical background. A theoretical foundation is defined by reviewing the literature which is present in the references of the theoretical frame. Based on these facts, we will focus on the analysis part using the references of the theoretical frame.

2.2 Scientific Perspective

2.2.1 Positivistic Paradigm
Basically the positivistic approach is theory based and it depends on explanations and description. Based on the deductions and discussions, the theories give a very strong framework. On the basis of logical, reasonable and rational approach this research is performed which is very systematic. In this approach the persuasions such as emotions, beliefs and feelings are not accepted because they are not tangible or objective and due to the reality that they are not constant across time. The aim of the approach is at the critical evaluation of all descriptions from the facts which can be guaranteed or validated with certain probabilities. The true knowledge and objectives are lead by falsifying and verifying theories and hypothesis.

2.2.2 Deductive Approach
For every deductive method, the base point is the theory behind it. The goal then will be to find some data based on the theory which supports the predetermined predictions made. The theory then concludes, what information should be collected? How it should be interpreted? And how the results can be related to the existing theory?
2.2.3 Qualitative Analysis

The qualitative analysis is more substantial and makes deeper understanding of a specific research area and a correct response to questions like ‘Why’. The qualitative analysis is regarded as soft data. This type of analysis aims at getting qualities which are neither reducible nor quantifiable to numbers like opinions, thoughts, feelings and experiences. Basically this approach is interpretive to knowledge and depends on the subjective analysis and verbal data and uses very less statistics and numbers.
3. PROBLEM ASSESSMENT:

3.1 Introduction

Natural resources are limited on earth but looking at the uncontrolled able consumption of construction material it is apparently unsustainable. Consumption of construction materials has compatibly increased along with production in the past century (Fig 3-1). Although there are few drops in the graph during 1940’s and 1990’s but no sustainability was employed for the economy of construction materials. With this trend of consumption of uncontrolled able construction materials will result in environmental degradation on a global scale and that will indicate extinction for humanity. In this chapter we will study the trend of consumption of structural construction materials of cement and steel, their environmental impacts and embodied energies.

![Figure 3-1: Trends of World and US. Steel and Cement consumption](image)

3.2 Trends in consumption

Based on the analysis from Figure 3-1 the consumption of cement has been mounting relatively high when compare to the consumption of steel throughout the world. Cement production is a major source of emissions of the carbon dioxide (CO₂) Figure 3-2. About
40% of the construction industry’s carbon dioxide emissions originate from cement production when to compare to the embodied energy of steel. Only one part of steel is consumed in construction industry when compared to all steel consumed. Cement is the major structural construction material used in the construction industry causing adverse environmental impacts.

![Figure 3-2: World and U.S. CO2 emissions due to steel and cement consumption.](image)

Cement and steel production increased at an incredible rate in the past century. Though the production of steel reduced after 1960’s whereas the production of cement continues to be relatively high as shown in Figure 3-1. The amount of steel and cement which was produced throughout the world in 2000 was around 800 million metric tons of steel and around 1.6 billion metric tons of cement was produced. The per capita production of steel and cement is shown in the Figure 3-3 at an interval of five years. As per the analysis 139 kg’s of steel and 271 kg’s of cement is required per person annually throughout the world. The demand for cement is relatively higher than compared to steel as per the figure.
Consumption of materials throughout the world depends mainly on two factors, firstly growth of the population and secondly the per capita production of the materials in the world. The growth of the population is been classified as low, medium, high and constant growth by the United Nations. Based on these classifications the production of steel and cement are illustrated at different levels of per capita production shown in Figure 3-4. Steel per capita production is assumed to be constant at 139kg's per person annually since the per capita production of steel is leveled out. The per capita production of cement is represented into two growth rates 5% and 10%. The growth rates of the per capita production have been extremely variable with the recent trend which showed 6% of growth rate in the per capita production. For the future per capita production the growth rates of 5% and 10% are more practical.
3.3 Environmental Impacts and Embodied Energies

In the Figure 3-5 different materials are compared to each other to see which has less or which has more embodied energy per unit weight. Comparative lists shows that steel embodied energy per unit weight is highest than the other materials.
The environmental impact of steel is worst when compared to other structural construction materials as per the Inventory analysis of Athena SMI reports. Steel is the worst when compared to concrete in terms of emission per unit weight. The environmental impact of steel and other structural construction materials in emission per unit weight are shown in Figure 3-6

![Figure 3-6 Emission per unit weight of different structural construction materials](image)

**3.4 Summary**

Due to the uncontrollable use of structural construction materials it is clear that with this current trend of consumption will lead to serious environmental hazards in the world. Steel has the worst environmental impact with highest emission per unit weight and has very high embodied energy. Comparatively performance of concrete is much better than steel per unit weight. Although consumption of cement and its global emission are extremely high when compare to the consumption of steel. To mitigate these environmental hazards new materials which has less environmental impact and which are
more environmental friendly will help from these material which are more harmful globally.
4. Recycling and Reuse

4.1 Introduction
The consumption of construction materials can be reduced through recycling and reuse. However, the consumption of materials always increases with the increase of the population. Even so, the only way to reduce the consumption of construction materials is to economize the use of materials, recycling and reuse. There are many trends and policies which are been used in the process of recycling and reuse of construction materials.

4.2 Recycling and Reuse

4.2.1 Recycling:
Recycling the land-filled waste construction materials reduces the use sage of the virgin materials as these materials already exist and to produce a virgin material huge energy is consumed with high percentage of emissions. One of the most recycling materials is steel which gets downgraded after recycling and to a large extent it can be recycled because structural steel is the lowest grades of steel. The other construction material which can be recycled is concrete and it gets downgraded after recycling.

4.2.2 Reuse:
The other way to reduce the consumption of construction material is to reuse the virgin materials. Annually million tons of waste material is generated due to construction, demolition or renovations of buildings. These constructions or renovations of buildings take place because of the shorter lifetime of the buildings and due to some changes in the usage of the buildings. With these kinds of changes in the construction of the buildings it is always possible to regain most of the useful materials from the wastage of the buildings efficiently and effectively, reuse them before the end of the materials lifespan. With this kind of method the consumption of the energy, cost and emissions are reduced.
4.3 Recycling and Reuse of Steel

4.3.1 Recycling of steel

There are two issues which we need to be considered when we discuss about recycling in construction industries.

1. How much amount of the used steel in the construction industries is been recycled?
2. How much amount of the recycled steel is used in the production of steel which is used in construction?

4.3.1.1 The amount of steel recycled in the construction industries.

Steel is also called “The EnviroMetal” as it is the most recycled metal on earth. Steel can be recycled over and over again without any losses of properties. Moreover recycling has grown in parallel with the increase in the consumption of steel. Steel is one of the highly recycled materials with 85% of the recovery rate from consumed construction industries. It is very difficult to separate steel from other construction materials and to estimate the end life of the steel.

Recycling trends are different in each industry. In construction industries it is always manageable to identity the sources of steel production but at the same time it is very difficult to calculate what happened to the steel at end of life. In construction, steel is mixed with other construction materials like for example concrete which is very difficult to separate but it is managed with different performances. Even after some performances some steel is simply land-filled like a worthless material. These land filled material is a mixture of steel and concrete and it is very difficult to calculate how much steel got recycled and how much was land-filled. From Steel Recycling Institute it is estimated that 95% of the construction steel is been recycled (Steel Recycling Institute, 2006)
Figure 4.1 Construction Structural, Recycling Rates (in Percent)
(Courtesy: http://www.recycle-steel.org/)

Figure 4.2 Construction Reinforcement, Recycling Rates (In Percent)
(Courtesy: http://www.recycle-steel.org/)
A targeted policy needs to be developed in recycling products to ensure which product is been recycled and which is not recycled. Form Steel Recycling Institute, 2006 it is estimated that (95%) of the bulky products like steel beams are highly recycled and only (50%) of the products like reinforcing bars are recycled with very low recycling rate this is because of the difficulties in separation of concrete from steel while recycling. From the figures 4.1 and 4.2, 4% of the reinforce bars and 10% of the sections are produced out of the total crude steel produced in the world. But it is always important that reinforce bars and sections should be properly recycled. Reinforce bars are decreasing all around the world according to the latest trends. Where in the world, reinforce bars doesn’t form as larger percentage of the total construction steel.

In brief, construction steel is highly recycled. Products like beams are awfully recycled whereas products like reinforce bars are not highly recycled and new policies should be introduced and designs to advance recycling of reinforce bars.
4.3.1.2 Composition of steel used in construction industry

To operate steel mills huge amount of fossil fuels are burnt resulting large amount of embodied energy. Steel has very high embodied energy and it is clear that due to high embodied energy steel is one of the most environmentally harmful construction materials when measured by weight. Concrete has low embodied energy because of low fossil fuel consumption with low emission when compared with steel.

In steel production construction steel is one of the lower grades steel and is 100% recyclable. Steel can recycled infinitely without any loss of quality. To create construction steel it is always possible to collect recycled steel from all other industries reducing the usage of energy and other raw materials.

From Steel Recycling Institute:

4.3.1.2.1 Basic Oxygen Furnace (BOF):

To produce new steel, basic oxygen furnace (BOF) uses 25% to 35% old steel. Where this furnace produces products like encaes of refrigerators, automotive cover etc whose major characteristic is drawability.

In 2006 by Steel Recycling Institute, to produce 46,802,100 tons of raw steel the basic oxygen furnace (BOF) consumed a total of 13,509,000 tons of ferrous scrap where 1,000,000 tons of these ferrous scrap tons had been produced as non-salable steel products. In steel industry, these tons of scraps are classified as “home scrap” which is a mixture of pre-consumer scrap and runarround scrap. By the Steel Recycling Institute it is estimated that 80% of the home scrap as pre-consumer scrap which is equating to 800,000 tons. For these kinds of operations during certain time frame 122,400 tons of superseded scrap is consumed. This kind of volume is known as post-consumer scrap.
Therefore from the above results the outside purchases of scrap is equal to 12,386,600 tons [13,509,000 - (1,000,000 + 122,400)].

![Blast Furnace](http://www.maccoal.com.au/Operations/Products/MetallurgicalProducts/tabid/96/Default.aspx)

*Figure 4.4 Blast Furnace*

According to the study of Fordham University the purchased ferrous scrap’s post consumer fraction would be 83.4% and the per-consumer of this purchase is 16.6% which equates to 2,056,200 tons (12,386,600 x 16.6%) of pre-consumer scrap.

The production process that generate the scrap for the products made with steel are the “prompt scrap”

Therefore, the total recycled content to produce the 46,802,100 tons of raw steel in the BOF is: 13,509,000 / 46,802,100 = 28.9%

(Total Tons Ferrous Scrap / Total Tons Raw Steel)

The post-consumer recycled content is:

(12,386,600 - 2,056,200) + 122,400 = 10,452,800

And 10,452,800 /46,802,100 = 22.3%
(Post-Consumer Scrap / Total Tons Raw Steel)
The pre-consumer recycled content is:
\[
\frac{800,000 + 2,056,200}{46,802,100} = \frac{2,856,200}{46,802,100} = 6.1\%
\]
(Pre-Consumer Scrap / Total Tons Raw Steel)
(Courtesy: Steel Recycling Institute)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Total primary energy consumption, MJ/ton steel</th>
<th>Total CO₂ emission, ton CO₂ /ton steel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Max.</td>
</tr>
<tr>
<td>Global average Coil and Plate (35 sites)</td>
<td>25 500</td>
<td>31 700</td>
</tr>
</tbody>
</table>

Table 4.1 Total primary energy consumption and CO₂ emission (global average, Blast furnace)

4.3.1.2.2 Electric Arc Furnace (EAF):

In 2006 by Steel Recycling Institute, to produce 59,126,400 tons of raw steel the electric arc furnace (EAF) consumed a total of 48,966,900 tons of ferrous scrap where 16,320,000 tons of these ferrous scrap tons had been produced as non-salable steel products. In steel industry, these tons of scraps are classified as “home scrap” which is a mixture of pre-consumer scrap and runaround scrap. By the Steel Recycling Institute it is estimated that 80% of the home scrap as pre-consumer scrap which is equating to 13,056,000 tons (16,320,000 x 80%). For these kinds of operations during certain time frame 358,300 tons of superseded scrap is consumed. This kind of volume is known as post-consumer scrap. Therefore from the above results the outside purchases of scrap is equal to 32,288,600 tons [48,966,900 - (16,320,000 + 358,300)].
According to the study of Fordham University the purchased ferrous scrap’s post consumer fraction would be 83.4% and the per-consumer of this purchase is 16.6% which equates to 5,359,900 tons (32,288,600 x 16.6%) of pre-consumer scrap. The production process that generate the scrap for the products made with steel are the “prompt scrap”

![Electric Arc Furnaces (EAF)](http://www.britannica.com/EBchecked/topic/art/32400/1531/An-electric-arc-furnace)

Therefore, the total recycled content to produce the 59,126,400 tons of raw steel in the EAF is:

\[
48,966,900 / 59,126,400 = 82.8\%
\]

(Total Tons Ferrous Scrap / Total Tons Raw Steel)

The post-consumer recycled content is:

\[
(32,288,600 - 5,359,900) + 358,300 = 27,287,000
\]

and

\[
27,287,000 / 59,126,400 = 46.2\%
\]

(Post-Consumer Scrap / Total Tons Raw Steel)

The pre-consumer recycled content is:
(13,056,000 + 5,359,900) / 59,126,400 = 18,415,900 / 59,126,400 = 31.1%
(Pre-Consumer Scrap / Total Tons Raw Steel)
(Courtesy: Steel Recycling Institute)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Total primary energy consumption, MJ/ton steel</th>
<th>Total CO₂ emission, ton CO₂ /ton steel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Max. Min.</td>
<td>Average Max. Min.</td>
</tr>
<tr>
<td>Global average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Section (4 sites)</td>
<td>11 200 15 300 8 600</td>
<td>0.54 0.77 0.31</td>
</tr>
<tr>
<td>- Rebar(10 sites)</td>
<td>11 800 16 400 5 000</td>
<td>0.59 1.08 0.15</td>
</tr>
</tbody>
</table>

Table 4.2 Total primary energy consumption and CO₂ emission (global average, Electric arc furnace)

Figure 4.6: Steel recycling
(Courtesy: http://www.worldsteel.org/)
Electric arc furnace (EAF) produces large amount of construction steel with a very high recycled rate. In previous chapter we have discussed and compared energy and emissions of virgin steel and virgin concrete.

![Figure 4.7: Comparison of energy and CO₂ emissions per ton of virgin steel, recycled steel and concrete](http://www.athenasmi.org)

(Courtesy: http://www.athenasmi.org)

### 4.3.2 Reuse of Steel

One of the main characteristic of steel buildings is that the buildings can be designed to simplify deconstruction or disassemble before the end of the useful lives. Reuse of steel has many environmental advantages; the steel components which are recovered from deconstruction or disassemble can be reused in future buildings eliminating the requirement of steel recycling. With this kind of reuse process the energy required for recycling or for producing virgin steel, CO₂ and other environmental troubles which are generated in the process of manufacturing construction steel is reduced. An additional advantage of designing buildings with the concept of reuse of the construction materials can reduce the pollution and disruption to the neighborhood. The possibility of waste going in to the landfill is also reduced.

### 4.4 Recycling and Reuse of Concrete
In structural construction material concrete is the other major building material. In this chapter we going to discuss about recycling and reuse of structural concrete. There are no standards for reuse of concrete unlike steel.

4.4.1 Recycling of Concrete

When concrete is recycled it gets scattered and gets downgraded. Crushed concrete aggregates engineering properties do not match with the virgin aggregate. Hence for structural purposes the crushed concrete aggregate is not used. It is used as a base material for pavements, roads, bridges, parking lot. With such ‘synthetic’ aggregates, ordinary Portland cement concrete does not bind well. Cement mix really well by absorbing with reactive magnesia and bind well with synthetic aggregates. Recycling of concrete aggregate would be encouraged by using this cement mix.

Between 1994 and 1996, according to AGC (Association of General Contractors) the use of crushed concrete aggregate with new concrete has increased by 170 percent, this means from every one mile of concrete pavement the amount of concrete that can be reclaimed is approximately 5,996 tons. According to AGC, large blocks of recycled concrete can be used as a material for shoreline protection and erosion control. The recycled crushed concrete can used as a base material for roads, drainage material placed around underground pipes, as a base material for footings and foundations, landscaping material, as an aggregate in new concrete.

In the past, when buildings were damaged or demolished the material was sent to the landfill all together but was not separated.

The trucking and tipping fees was paid by the demolition company. With the help of separating machine, all the waste was sorted at the landfill. Then the recycled material was selling by the landfill to the construction companies and steel mills. The construction companies used the crushed concrete as aggregate and the steel as scrap material.
But now a business opportunity has been identified by the construction companies. A demolition waste separating machine is hired or bought by the company doing the construction. Using the crushing machine the separated material is recycled on site for concrete and steel is sold as a scrap material to the steel mills. All other material that is left is used selectively for land filling. The cost of buying the aggregate is saved and also the cost of trucking and tipping is also saved. The cost saving figures reported is different on several websites. According to Waste-Handling website the cost saving ranges from $8-$9 per ton of material and according to AGC website the cost saving ranges from $100 per ton of material. As per the current reports, the construction waste that is recycled on site or at the landfill is approximately 85-95%.

For recycling the concrete, companies which do the ‘reprocessing’ charges a fee but when compared to the landfills, there charges are half of that of landfill. After recycling they sell the recycled steel as scrap to mills and the recycled concrete is crushed and washed, and sell it as aggregates. As per the information from Madison Environment Group 2001, the ‘reprocessing’ firms which charge a fee for recycling from the
construction companies are, for recycling steel it is $3.77/ton and for recycling concrete it is $6.72/ton. Recycling has been encouraged because of the economics of buying new materials.

### 4.4.2 Reuse of Concrete

Due to concrete’s density and deficiency in modifying, the reuse of concrete is attended by difficulty. In the event of cast in place concrete, it is specifically true. In the massive construction like the footings, foundations, shear walls, concrete columns, concrete slab, etc it is used as filling materials and reuse is prevented. In demolished buildings, concrete is reused on the same site as the structural skeleton in the new building. This kind of situation can be considered as renovation instead of considering it as a demolition followed by reuse.

### 4.5 Summary

Recycling and reuse of the construction materials abate the consumption of raw materials to a great extent. Reuse of structural members is not that developed but recycling is considerably practiced well. By recycling the concrete, the concrete gets downgraded and it is used as filler aggregate. Whereas by recycling the steel, the construction steel grade improves. In construction industry, the material which is mostly recycled is steel with 85% to 95%. In recycling sections like structural sections have high recycling rate than reinforcing bars because separating reinforce bars from concrete in very difficult. It is estimated that construction steel has nearly 95% recycled content but the embodied energy used for recycling steel is almost ten times greater than that of the energy used in recycling concrete. In reuse, energy and cost can be saved. The main obstacle in reuse is the lack of design standards and regulations for structural sections, and market for reusable structural sections. Some of the recommendations for advancing recycling and reuse are developing design standards, regulations for structural sections and market for reusable sections, increasing lad-fill fees and encourage organizations in backing up recycling and reuse.
5: Material Selection

5.1 Introduction

This chapter describes briefly on the selection of material to reduce the environmental impacts and the role of the designer in the selection of the material in the construction industry and the problems faced by the designers for environmental performances. Selection of materials is a privilege to the product designer. In most of the industries many scientific techniques are developed for the selection of materials so that it gives less environmental impacts. But in the construction industry these techniques falls behind.

Life Cycle Assessment (LCA) technique is the most prominent technique used by the designers in all industries. In the automotive industries, design evaluation even at the conceptual stages is clearly developed on environmental performance for example Volvo which initiated the EPS system (Environmental Priorities Strategies) for the selection of material. The Eco-indicator system is developed in Netherland by the Pre Consultants which is used in other industries by the product designers. In Europe both of these systems are begin used by the designers in the construction industries. The Life Cycle Assessment technique is used in the construction industry by the designers in general but not well acquainted with the technique. Moreover, the designers do not have sufficient tools at their disposal.

The tools which are available for the designers in the construction industry are critically examined for the selection of the materials. Based on the Life Cycle Assessment (LCA) methods it is important to discriminate between Material Selection Tools and Life Cycle Assessment Tools. There are many LCA tools which are based on different evaluation methods, similarly for the material selection tools there can be different evaluations based on the same LCA methods. The TRACI which is the U.S. EPA LCA tool gives the basis for both BEES and ATHENA material selection tools. All the three TRACI, EPS system and Eco-indicator system are Life Cycle Assessment (LCA) tools. Henceforth it is the
data which goes into the material selection tools which is generated by the LCA tools therefore it is important to study or examine the LCA tools.

5.2 Designer’s Role

For the designer it is a privilege of selecting material which is an integral part of the design. Today the main reasons for selecting materials in unscientific process are due to the lack of standards and not compatible contribution from the industry. From the material industry there are many conflicting statement which is also one of the reason for selecting materials. Concrete is claimed by the concrete industry to be the most sustainable material as it is made from waste material (The Concrete Centre) and has very low embodied energy. Timber is claimed by the timber industry to be the most sustainable material as it renewable (National Association of Forest Industries) and completely natural. Steel is claimed by the steel industry to be the most sustainable material as it highly recycled (Steel Recycling Institute). To get the desired results in there favor these industries select there own measures which are not compatible for the designer in selecting materials. So there is always a need for the production industries like Concrete, Timber and Steel to establish a standard methodology which scientifically evaluate according to the perspective of environment credentials.

In the construction industry as there is no general agreement on the methodology for selecting materials due to disorganized nature of the construction industry itself. Even for the life cycle assessment methodology there is no general agreement amongst the researchers for the best method. Furthermore, there is lot of confusion with the number of LCA tools available. To implicate this methodology for selecting materials the designers should be educated in the LCA tools to decrease the environmental impacts.

5.3 Tools for the Designers for selection of construction materials

A list should be made about the all products with their life cycle costs and their environmental impacts which will help the designer. The TRACI which is the U.S. EPA
LCA tool gives the basis for both BEES and ATHENA material selection tools.

5.3.1 BEES (Building for Environmental and Economic Sustainability)

One of the LCA tool called BEES “Building for Environmental and Economic Sustainability” is a very good tool which meets the designer needs. BEES have ten impact categories. It requires relative values to be allotted by the user to different impact categories like acidification, global warming, etc. BEES require weighting where as the designers are not able to weight the environmental impacts as they are not experts in environmental assessment.

5.3.2 ATHENA

Unlike BEES which is a product comparison tool, ATHENA is an assessment tool for the whole building. The different types of assemblies which are used in the construction are there in the database of ATHENA tool. By describing the different assemblies which are used in the construction like roofing, foundations, etc, entire building can be described in ATHENA. The user is required to describe the type of assembly and the parameters of the assembly type. ATHENA is a complex tool and it is not useful to the designer as BEES.

The impact of energy consumed by the building during its lifetime is known by its design. To calculate the energy of this building by ATHENA it could apparently ‘evaluate’ design. Though, ATHENA does not do that. ATHENA will ask the user the information of the annual energy consumption. So it is not clear about the usefulness of recreating the entire building. In ATHENA the environmental impacts are calculated per unit weight of materials, unlike BEES it will be of more advantage to just list the environmental impacts per unit weight of materials. When compared to BEES, ATHENA is more complex as it requires to weight for different impacts by the user.
5.4 Significance of LCA tools

BEES and ATHENA are the two materials selecting tools which were examined to meet the needs of the designer in selecting materials and the tool which was confine to be the most helpful was BEES. BEES disadvantage is that it needs a relative value to be allotted by the user to different impacts like acidification, global warming etc. BEES require weighting where as the designers are not able to weight the environmental impacts as they are not experts in environmental assessment. It is very important to understand that different LCA tools are required for weighting which is derived from LCA tools by generating the data that goes into material selection tools.

The environmental impacts caused by the materials need to be determine by designing a tool which will help in selecting materials. But it is very difficult to determine the different types of impacts caused by the materials. For example a material may emit nitrogen oxide, carbon monoxide and these causes several types of impacts and simultaneously these materials will also consume resources. Hence these impacts are analyzed and characterized as “Impact Categories” to know their interacting effects. But the problem of weighting is still not agreed by the scientists as the issue of valuing of one impact over the other impact category is still unresolved.

According to the designer’s outlook the best and easy way would be to use a single impact category as different impact categories will use different LCA approaches. For example EPS (Environmental Priorities Strategies) system is one approach which specifies the impacts in economic conditions but this system is regarded as subjective. The categories which can be understood without any troubles and which has least categories are the Eco Indicator system which has three categories- ecosystem health, human health and resource depletion. These categories can be listed as per the priorities of the designers.
On the other hand TRACI approach which is used by the BEES has ten categories which are very difficult to understand and difficult to list them according to their impacts. It is very difficult for the designer to assign equal weights for all categories. As some categories have impacts which are greater but in a very short time. They are more critical when compared to others and are granted more importance. EPA guideline or the Harvard guidelines are the other methods of weighting which are available for the designer to use but it is very difficult for the designer to distinguish between them. Similarly Eutrophication is the category which is not understood in general. If the results are available in a common language such a way that the designer can understand then it is very easy for the designer to implicate them of their choices.

It is very easy to weight in Eco- indicator but it is very difficult to weight in TRACI system. The system which has inherent weighting is the EPS system where the monetary weighting values of the society can be referred to specific environmental hazards. But as the weighting values of the society keep changing it is definitely a challenge so this methodology is not treated scientifically.

From the above discussion we can conclude that the Eco-indicator is the best assessment approach with a single weighting system and the categories are easily understood which makes the weighting easy thus making it very useful to the designer.

5.5 Summary
The summary of this chapter is that the tools which are used for selecting materials are made available for the designer. BEES system was regarded as the most suitable for material selection tool. But the disadvantage of the BEES is that it requires ten weighting categories based on TRACI LCA approach. Whereas The EPS and Eco-indicator which are based on LCA approach are made easier by eliminating the weights. Finally it depends on the designer to decide which LCA approach is better. We will discuss and analyze the most suitable methodology in selecting materials through LCA approaches.
6: Life Cycle Assessment Approaches

6.1 Introduction

The environmental impact of a product is assessed at all stages of life by the inclusive LCA tool. A life cycle assessment method investigates a product’s life cycle and creates an input-output inventory of the product at each phase necessitated by its existence. The life cycle of a product starts with raw material extraction, followed by manufacturing and then transportation, use and finally waste management which include recycling and disposal. Figure 6-1 describes the life cycle of a product.

An input-output inventory document is formed as there is consumption and emission at all stages of the product life cycle. The input-output inventory of a product is shown in Figure 6-2. The input-output inventory data is then assessed to decide how it impacts the environment. For example, Global warming and acidification might be the two different impact categories. In LCA, assessment of the impact is the most crucial step as it creates differences amongst the methodologies. There are many methodologies for assessing the impacts which might give contradictory results. According to ISO 14040, “Comparing the different results of LCA studies is possible when the context and assumptions of each
study are same. These assumptions should be clearly demonstrated for transparency”. This means ISO agrees that the results of LCA will differ depending upon the type of approach used for the same product.

![Development of an LCA inventory](http://www.lbl.gov/publicinfo/newscenter/features/2008/apr/assets/img/hires/LCA.jpg)

*Figure 6-2 Development of an LCA inventory*  
(Courtesy: http://www.lbl.gov/publicinfo/newscenter/features/2008/apr/assets/img/hires/LCA.jpg)

If the results are different depending upon the type of approach, how can we decide which approach is best? And which approach to select? Which result is more accurate? All these questions are the pivotal points in this chapter. The main feature of this chapter is to determine and analyze which LCA approach is most accurate and suitable.

### 6.2 Four Main phases of LCA

According to ISO 14040, a Life Cycle Assessment is supported by four main phases.

1. Goal and scope
2. Life cycle inventory
3. Life cycle impact assessment
4. Interpretation
6.2.1 Goal and Scope

According to ISO 14040, the definition of the goal should include the intended application, should have reasons to carry out the study and the intended audience.

The scope of any project needs the description and definition of functional unit, product system and system boundaries, impact assessment, producers for allocations, illustration methods, etc. Among all the issues in goal and scope the two most important issues are describe below:

6.2.1.1 Definition of functional unit:

The unit of a product is defined by the functional unit which is carried out for life cycle assessment. For example, the functional unit of a construction material could be 1kg of the material. The goal of the project will depend on the choice of the functional unit. Say for a particular construction project the goal is to compare the impacts of steel and concrete. For that particular project a material of 1kg functional unit is not useful since comparing to 1kg of concrete, 1 kg of steel can support more load. The amount of material needed for supporting the unit load will be the useful
functional unit. When different materials are compared a particular definition of a functional unit is required.

6.2.1.2 Product system and system boundaries:
In the analysis it is necessary to define the product system and system boundaries to ascertain which impacts and processes will be part of the analysis and which one will be removed from the analysis. For example, in mining when impacts are identified will that include the impacts caused due to production of drill?

6.2.2 Life cycle inventory

During the life cycle aspect of a product or a project the data which is collected about the environmental impact is the life cycle inventory. This is done by modeling life cycle processes or by estimation or by measuring point emissions. In data collection the issues which are important are describe below:

6.2.2.1 Effects due to Time:
During the life cycle of a product it is important to ascertain when the impact occurred for documenting the impact of the product and all the impacts required to be deducted to the present. For example, the chemicals which are emitted to the environment will decay at some point of time. Eventually the harmful effects of the chemical are limited with time. Scientifically methane which is emitted to environment will oxidize into CO$_2$ and will stay in the environment for a period of 12 years. Eventually the harmful effects of methane will last for 12 years and slowly decay in those 12 years of time. Today when a product emits methane, it is important to know that the same product does not have the same impact of methane emitted after 10 years.

6.2.2.2 Effects due to Geographical:
The environmental impact of a chemical depends on the concentration of the chemical at that existing time and the density of the local populations. The characteristic of the chemical changes from one place to another. In one region the manufacturing impact of
the chemical may occur and in another region lifetime and disposal impacts may occur. Many chemicals have localized impacts like for example the impact of 1g of NO\textsubscript{x} is different in New Hampshire and Los Angeles whereas the impact of CO\textsubscript{2} is global.

6.2.2.3 Effects due to Technology:
Different impacts are produced by the uncertain efficiencies of different technology.

6.2.2.4 Allocation procedures:
In a system when multiple products are included allocation procedures are required. For example in the production plant of steel, fly ash is also produced as a waste product in the same plant. The fly ash can be disposed or can be sold. The emissions and the resources used should be allocated only for steel or they should be shared equally between steel and fly ash.

6.2.3 Life cycle impact assessment
The life cycle impact assessment is described as follows:
The input-output inventory of a product’s life is collected in data collection step. But this data does not give a clear description of the harmful impacts caused due to for example, 3kg of CO\textsubscript{2}. Therefore this data is required to be converted into impacts which are easy to understand. Impact categories are required to entitle and in each of these categories these Impacts are ascertain. The Life cycle impact assessment is described in few steps:

1. Global Warming
2. Acidification
3. Ozone Depletion
4. Eutrophication
5. Human Health
6. Resource Depletion
7. Terrestrial Toxicity
8. Photochemical Smog
9. Aquatic Toxicity
10. Land Use
6.2.3.1 Impact categories identification:
By using the resources or by emission there are particular negative effects to the environment which are identified as impact categories. For example global warming is caused by the emission of CO$_2$; here the impact category is global warming.

6.2.3.2 Definition of impact indicator and impact indicator units:
Impacts are measured in units which are impact indicators. For example, Through DALY (Disability Adjusted Life Years) a human health is determined. Here person’s years is the unit of impact indicator.

6.2.3.3 Different Classification:
Each of the resources or the emission used must be summarized to evaluate the damages done by using the resources or emission and then to see which impact categories they affect, they must be examined thoroughly. This is known as classification of the resources or the emissions used into one or more categories as each emission can causes one or more hazards. For example eutrophication and human health are caused by NO$_x$.

6.2.3.4 Impact characterization:
By using a distinct formula the resource or the emission depletion inventory is converted into equal quantities of impacts. For example, Methane is ascertained to have GWP 23 times that of CO$_2$. It is converted as 1kg of methane’s GWP is characterized to be 23kg equivalent of CO$_2$.

6.2.3.5 Normalization and weighting:
The processes in which an impact is compared with the total impacts caused in the country to that of the impacts of all sources in a year is called Normalization. Weighting is a procedure in which the relative importance of different impact categories is created. According to ISO normalization and weighting are not compulsory.
6.2.4 Interpretation

The interpretation stage is the most important. The inventory analysis helps to come to the conclusion by comparing the results set from goal and scope stage. When comparisons are made as they are being used in public province independent critical examination is required. Therefore by making inclusive assessment of the inventory analysis and impact assessment, final conclusions and recommendations are made.

6.3 Approaches for Impact Assessment

There are different impact assessment approaches available to know the environmental impact of a material. A different approach gives different results as there are no confirm standards for impact categories and methodology for weighting. There are no general agreements available which can help in selecting the type of approach. An immediate attention is required for promoting the LCA use and for that a compatible policy needs to be express precisely. To understand the differences between the approaches and formulate a compatible policy, we need to study the following three different LCA approaches.

The following are the three impact assessment methodologies:

1. TRACI
2. EPS
3. Eco-indicator.

In every approach impact categories are defined by impact indicators and each indicator is expressed by specific indicator units. Each chemical has a characterized factor which is expressed by specific indicator units. For example Global Warming is the impact category; it’s impact indicator is Global Warming Potential, it’s impact indicator unit is Kg of CO₂ equivalents and as mentioned each chemical has a characterized factor like for example say CO₂ has the characterized factor 1 and for CH₄ the characterized factor is 23, all this signify that methane has the capacity to effect the global warming of 23 times when compare to carbon dioxide.
6.3.1 TRACI - Impact Assessment Approach

For impact assessment TRACI software is created by the U.S. EPA. As the requirement of the software the input inventory data which is calculated by the amount of resources consumed and emitted which are further described and classified to produce final normalized score for different impact categories. Table 6-1 gives the list of ten impact categories and a chemical emission will contribute to one or more impact category.

Figure 6.4: Graphical representation of TRACI
(Courtesy: http://www.epa.gov/nrmrl/std/sab/traci/)

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Impact Indicator</th>
<th>Scale</th>
<th>Indicator Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming</td>
<td>Global Warming Potential</td>
<td>Global</td>
<td>CO₂ equivalent</td>
</tr>
<tr>
<td>Acidification</td>
<td>Acidification Potential</td>
<td>Local/Regional</td>
<td>H⁺ ion equivalent</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>Ozone Depletion Potential</td>
<td>Global</td>
<td>CFC-11 equivalent</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>Eutrophication Potential</td>
<td>Local</td>
<td>PO₄ equivalent</td>
</tr>
</tbody>
</table>
Table 6-1: Life Cycle Impact Categories in TRACI

The impact categories are classified from life cycle inventory data which are multiplied by related characterized factor developed by the emission of each chemical. In each category the scores are added to produce the total impact of that category.

With the help of TRACI we can resolve ten impact categories with relevant impact indicator and for chemicals we can develop the characterized factors. It is not easy for the designer to differentiate between the categories without weighting. It is a difficult task to understand the impact of ten impact categories and assigning weights to them is not easy without knowing what that category means exactly. In TRACI the location and temporal effects are not been taken under considerations. The environmental impacts are caused due to the timing and concentration of the existing emission. Henceforth, these analyses are not reliable and thus are not included.

6.3.2 The Environment Priority Strategies (EPS) system

In Sweden the Environmental Priorities System (EPS) was developed in Chalmers University of Technology within the Centre for the environmental assessment of Product and Material system (CPM), along with industry participation. For product development process EPS system is the tool. The environmental load caused due to their product is calculated by this tool which is very easy to use for the designer. TRACI has two major
differences a) the results which are represented in ELU (Environmental load unit) are equivalent to Euros which is a monetary measure, and b) the results are represented as single scores.

For designers, LCA is made easy with the help of this system. This system has its own acknowledge inherent subjective valuation, which is not evident. To develop the system a subjective economic valuation is implicated. In OECD (Organization for Economic Co-operation and Development) countries, a default database for valuation system is developed by EPS. In characterization factor the uncertainty involved is clarified and the uncertainty factor is associated with each of the characterization factor.

6.3.3 The Eco-indicator system

The Eco-indicator was developed in Netherlands by Pre Consultants and was authorized by the Dutch Ministry of Housing. Eco-indicator has three safeguard subjects, alternative to impact categories in TRACI. An impact is not expressed in economic units unlike EPS approach and even in the methodology valuation system is not implied.

In eco-indicator system, default weighting are extended and the safeguard subject can be weighted at the end. But if the designers are not willing to use the default weighting than an advance weighting guide is available for the designers. It is very easy to understand for the designers as the three safeguard subjects’ resources, human health and ecosystem can be weighted easily when compare to TRACI. To get three main impacts in the areas of resources, human health and ecosystem, all impacts are added based on the inventory emission of product.

With the help of normalization factors and pre calculated weighting all the three impacts are normalized and weighted. Apparently time, location and uncertainty effects are described integrated. The environmental parameters like the existing levels of chemicals, population densities are of the European environment as the method is specifically developed for Europe. The development of a weighting system is most useful. All
possible weighting sets are compared with the products outcomes which are described graphically in the triangle. Combination of weights is represented by each and every point in the triangle that adds up to 100% and it is very important to develop the consensus with the concept of “indifference lines”.

Figure 6-5: The Eco-indicator weighting triangle

(Courtesy: http://www.pre.nl/eco-indicator99/triangle.htm)
6.4 Summary

The summary of this chapter is that in TRACI methodology there is no consensus available on weighting and it is very difficult to understand. As described in chapter 5 the BEES software uses TRACI system. Allocating exact weights to all impact categories is the difficult task for the designer in the weighting. As few impact categories are more severe than others, and few impacts are short term which need to be allocated carefully. With the help of Harvard guideline or the EPA guideline it will be easy for the designer for weighting. But the designer cannot differentiate between the available alternative weightings in any case. For the designers to understand their assumption of their choice it should be available in common language like for example one of the impact categories like “Terrestrial Toxicity” which is not understandable for common man.

All the three systems TRACI, Eco-indicator and EPS system studied helps for single score calculations, which is very easy to use. While it is difficult for weighting in TRACI system, whereas weighting is easy in Eco-indicator system. EPS system has inbuilt weighting system. These weights are the commercial values to specific environmental problems which the society are connected. But as these values keep changing in the society it is very difficult and questionable. Hence these methodologies are not scientific.
### 7: ANALYSIS

<table>
<thead>
<tr>
<th></th>
<th>STEEL</th>
<th>CONCRETE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling</td>
<td>Very High</td>
<td>Medium</td>
</tr>
<tr>
<td>Reuse</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Energy Consumption</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>CO(_2) Emission</td>
<td>High</td>
<td>Medium/Low</td>
</tr>
<tr>
<td>Resource</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Depreciation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Landfill</td>
<td>Very Low</td>
<td>High</td>
</tr>
</tbody>
</table>

Table 7-1: Analysis: Steel and Concrete
7.1 Recycling:
In case of Steel and Concrete, Steel is one of the highly recycled materials and it is also called “The EnviroMetal” as it is the most recycled metal on earth. Steel can be recycled over and over again without any losses of properties. Form Steel Recycling Institute, 2006 it is estimated that (95%) of the bulky products like steel beams are highly recycled and only (50%) of the products like reinforcing bars are recycled with very low recycling rate this is because of the difficulties in separation of concrete from steel while recycling. Where as concrete when recycled it gets scattered and gets downgraded. Crushed concrete aggregate’s engineering properties do not match with the virgin aggregate. Therefore from the above statement and from chapter 4 twe can say that recycling of steel is very high when compared to recycling of concrete.

7.2 Reuse:
The steel components which are recovered from deconstruction or disassemble can be reused in future buildings eliminating the requirement of steel recycling. But in the case of concrete due to its density and deficiency in modifying, the reuse of concrete is attended by difficulty.

7.3 Energy Consumption:
To operate steel mills huge amount of fossil fuels are burnt resulting large amount of embodied energy. Steel has very high embodied energy and it is clear that due to high embodied energy steel is one of the most environmentally harmful construction materials when measured by weight. The energy consumption for virgin steel is high when compared with recycled steel. Concrete has low embodied energy because of low fossil fuel consumption with low emission when compared with steel.

7.4 CO₂ Emission:
In the case of virgin steel production or recycling steel huge amount of fossil fuels is burnt resulting with high CO₂ emissions. But in the case of concrete less fossil fuel are consumed in the process of production resulting with very low CO₂ emissions.
7.5 Resource Depreciation:
In steel production construction steel is one of the lower grades steel and is 100% recyclable. Steel can recycled infinitely without any loss of quality and to create construction steel it is always possible to collect recycled steel from all other industries reducing the usage of energy and other raw materials. Because of high recycling rate there is always a possibility for low resource utilization reducing the production for virgin steel as it is already exist. Concrete, this is man-made material composed of cement, slag cement and fly ash aggregated with sand, water and chemicals. Because of high use age of concrete in construction and low recycling rate concrete utilizes more natural resource resulting with high resource depletion.

7.6 Production:
Due to high recycling and reuse of steel the production of virgin steel is low as it is already exist. But in the case of concrete due to low recycling and reuse of the existing concrete the production for concrete is high.

7.7 Landfill:
In steel, construction steel is 100% recyclable. In construction, steel is mixed with other construction materials like for example concrete which is very difficult to separate but it is managed with different performances. Even after some performances some steel is simply land-filled like a worthless material. These land filled material is a mixture of steel and concrete.
8: CONCLUSION

8.1. Overview
This thesis determined some of the problems of unfavorable environmental impacts which are raised due to the use of construction materials and to mitigate these environmental impacts two trends are discussed in previous chapters.

8.2. Problem Assessment
To the global environmental impact construction materials gives substantial influence. If there is no development in reducing these environmental impacts and if the same old trends are continued more and more global environmental impacts may occur in the near by feature such as melting of ice, tsunami, slowing of ocean currents etc. Huge emission from all kind of sectors needs to be reduced and even if these emissions are reduced today, the atmosphere takes long time to make resistant to the changes. More over in the meantime there may be disaster in markets and losses of lives. In the present world there is a huge demand for steel and cement, cement itself contributes over 6% to global emissions and substantially to energy consumption. The growing trends and production of construction materials are serious threats to natural resources, climate and energy. Serious actions need to be taken by designers and engineers to overcome this treats. To mitigate these threats two trends are addressed in this thesis they are - reduce consumption and material selection.

8.2.1 First Strategy: Reduce consumption
In practical complete reduction in consumption of materials is not possible but this strategy focuses on recycling and reuse of construction materials. Recycling of steel and concrete is highly practiced; concrete when recycled produces a rough aggregate which is used as a filter material for foundations, footings, bridges, parking places, roads etc. The other way to reduce the consumption of construction material is by reuse of sections.
8.2.2 Second Strategy: Material selection

Acknowledgment of environmental issues is frequently not considered as design criteria for buildings. Because of this material selection is made independent of environmental consideration. In this thesis, for different material selection in the view of environmental consequences we discussed about an important method called LCA (Life Cycle Assessment). In material selection tools for the structural designers we have studied about two tools BEES and ATHENA. Out of these two tools BEES is the most useful tool, BEES have a database of different materials with their life cycle costs and their life cycle impacts. In BEES, environmental performance of different materials can be compared by the user. One of the main drawbacks of BEES in normal user prospective is it displays environmental performance in 10 different categories and out of these 10 categories the final result may have no meaning because the user may not understand.

In LCA method we studied about three different approaches – Environmental Priorities Strategy (EPS) gives the end signal scores in the form environmental load unit, The TRACI (Tool for Reduction and Assessment of Chemical and other Environmental Impacts) which is used in BEES gives 10 categories as the final result, which is very difficult to understand. Whereas the Eco-indicator gives 3 categories as the final result, which is very easy to understand and can be weighted. So among these two approaches Eco-indicator and TRACI, Eco-indicator was recommended to the designers as the LCA tool.

8.3 Final Conclusion

1. Construction materials are harmful threats to the environment; these threats are increasing with the increase in the population and consumption of construction materials.
2. The environmental impacts can be contended by implementing certain objectives to reduce consumption, and for design integrate environmental proceedings as a specific standard rules.
3. Recommendations:

i. To reduce consumption: To advance reinforce bars recycling, certain policies need to be planned and introduced. For reuse of structural sections design standards and regulations need to be established and for reusable sections functioning market should be developed.

ii. For material selection: Material selection tools like BEES need to be promoted through education of designers. The database of materials in BEES should to be enlarged. The LCA tool TRACI must be upgraded to reduce the number of impact categories which is very difficult to understand, make these categories understandable and introduce uncertainty data.
Reference:

9.1 Literature


9.2 Internet links

Wikipedia:

**Cement.org**

**Corus Construction.com**

**Worldsteel.org**

**Recycle-steel.org**

**Sustainable-steel.org**
http://www.sustainable-steel.org/, 2009
Lca.cz  

Life Cycle Initiative  

United Nations Environment Programme  

Concrecentre.com  

Industrial-energy.lbl.gov  

Building and Fire Research Laboratory  

Cmit.csiro.au  

Firstenvironment.com  

Buildinggreen.com  
U.S. Environmental Protection Agency

Steeluniversity.org
http://www.steeluniversity.org/content/html/eng/default.asp?catid=113&pageid=2081271369, 2009

World Building Design Guide

Buildings.com

Building.co.uk

Worldofconcrete.com

Johnjing.co.nz

Reuse-steel.org

Lca.jrc.ec.europa.eu
Ecobilan.com
http://www.ecobilan.com/uk_lca05.php, 2009

Athenasmi.ca

Dev.hil.unb.ca

Odyssee-indicators.org

Victoria.ac.nz

Mitpress.mit.edu/journals
http://mitpress.mit.edu/journals/pdf/jiec_6_3_49_0.pdf, 2009

Unep.fr

Eetd.lbl.gov
Sorell.dm
http://www.sorell.dm/newsletters/V5-07-06.pdf, 2009

Climatevision.gov

Lcacenter.org

Gundog.lbl.gov
http://gundog.lbl.gov/dirpubs/BS01/BS01_739.pdf, 2009