Environmental Impact Assessment for Sustainable Cement Production

By

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A thesis submitted in partial fulfilment of the requirements
of Edinburgh Napier University for the award of

Doctor of Philosophy

PhD

March 2013

ABSTRACT

Cement production requires intensive use of natural raw materials and energy. It also results in emissions to the atmosphere, the most significant being CO_2. Studies estimate that the cement industry is responsible for 5% of global man-made CO_2 emissions. Managing and reducing these emissions is therefore a key priority. Cement emissions come from the following sources: chemical clinker-making process (50%–60 %), combustion of fossil fuels (40%), and indirect emissions from purchased electrical power (5%). This research has been carried out with the main objective of assessing the environmental impact of cement production and the potential for reducing its CO2 emissions. To achieve this objective, the performances of three cement companies were investigated and specific indicators set to measure the development of each company and benchmark the performances against each other. The research takes into account social, economic and environmental factors. The assessment used in this study is based on the WBCSD initiatives and its sustainability approach to cement production.

This assessment has been conducted by indicating the best performance cement company and displaying the weak points of each of the benchmarked companies. This benchmark was used not only to estimate the environmental impact of cement operations and production among best performance companies, but also to determine new opportunities for efficient cement production, energy efficiency consumption, and low CO_2 emissions. This study used the benchmark to analyse the Lafarge, Holcim, and Taiheiyo cement companies.

The research investigation is based on the review and analyses of data collected during authorised visits to the operating sites of each of these cement companies. Further required data was obtained from the companies' Sustainable Development Reports. A procedure for developing comparable environmental performance indicators, useful for benchmarking, has been described. This procedure has been used to develop key Environmental Performance Indicators, also taking into account economic and social performance. Both strengths and weaknesses are pointed out in different sections of the case studies. First, the benchmark, the resources to be included and the return figures play a determinant role in the quality of the results. Second, the assessment of environmental performance was evaluated by using specific indicators, including the imperatives indicators to investigate options for reducing CO_2 emissions throughout the process of manufacturing.

The chief original contribution of this research is to identify the opportunities and potential for reducing the CO_2 released from cement production, and to develop a model to allow evaluations to be made at different times during the cement manufacturing process of different cement companies, with varying priority levels of selected environmental performance indicators. Recommendations are made to manufacturers and the cement market in order to achieve higher levels of environmental performance (that is, less CO_2 emissions). This work opens new horizons for further research in this field.

ACKNOWLEDGMENTS

I wish to express my gratitude to all people without whom this study would not have been possible. I am grateful to my supervisors, Prof. Tariq Muneer, and Mr. John Wood, who provided critical discussion throughout the work on this thesis. My initial steps towards a lifetime project are credited to their patience, support and encouragement.

I cannot precisely verbalize appropriate words to express my deep appreciation to, Prof. Naren Gupta and Prof. Brian Sloan, and to each of Lafarge, Holcim, Taiheiyo Cement companies who approved using their data in this thesis.

I would like to thank my husband Dr. Ahmad Makkawi for his sacrificial support, understanding and assistance in every situation of my journey. I would like to extend special gratitude to my parents: Dr. Yousef El Atasi and Dr. Seham Zeno; and my sisters: Dema El Atasi and Housen El Atasi for their special support and encouragement.

With great and special thanks to my beloved children: Mahmoud and Yousef Makkawi who filled my life with the greatest happiness that a mum could have.

DECLARATION

I hereby declare that the work presented in this thesis was solely carried out by myself at Edinburgh Napier University, Edinburgh, except where due acknowledgement is made, and that it has not been submitted for any other degree.

…………………………………………………..

Loubana El Atasi (CANDIDATE)

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Date 27. 01.2013.

Table of Contents

Abstract

Acknowledgments

Declaration

Table of contents

List of figures

List of tables

Abbreviations

Glossary of terms

Pages

Chapter-1 Introduction **1-11**

1.1 introduction

1.2 Sustainability Indicators (SIs) and Environmental Performance Indicators (EPIs)

1.3 Research Aim, Objectives, and Scope of Activities

1.3.1 Research Aim and Objectives

1.3.2 Scope of Activities Covered by the Plan

1.4 Thesis Outlines

Chapter-2 Literature Review **12-55**

2.1 Introduction

2.2 Review of cement consumption worldwide

2.3 Review of cement production across the world

2.4 Cement properties: composition

2.5 Cement production: description of manufacturing process

2.5.1 Raw materials preparation

2.5.2 Clinker production (burning in kiln)

2.5.3 Clinker cooler and finish grinding

2.6 Energy use for cement making

2.7 Emissions from cement production

2.7.1 CO_2 emissions from raw materials calcination
2.7.1.1 Clinker
2.7.2 Carbon dioxide emissions from conventional kiln fuel
2.7.3 Carbon dioxide emissions from alternative fuels (AF)
2.7.3.1 CO_2 from biomass fuels
2.7.3.2 CO_2 from fossil fuel-derived wastes
2.7.4 CO_2 emissions from electricity
2.8 Total CO_2 emissions from cement production
2.9 Energy efficiency improvement and CO_2 reduction opportunities
2.9.1 Replacing high carbon fuel with low carbon fuel (waste used as fuels and ARM)
2.9.1.1 Recycling and reuse of waste materials to recover energy
2.9.1.2 ARM usage in cement manufacturing process
2.9.2 NOVACEM magnesia cements (Reactive magnesia cements)
2.10 Carbon dioxide removal (cement carbon capture and storage, CCCS)

Chapter-3 Research Methodology 56-68

3.1 Sustainable development, WBCSD and the cement industry
3.2 WBCSD sustainability initiative and the cement industry
3.3 The research program (Toward a Sustainable Cement Industry)
3.4 Response of the cement industry to the WBCSD

Chapter-4 Case study for Lafarge Cement Company worldwide 69-96
4.1 Lafarge commitment to the WBCSD
4.2 Environmental commitments
4.2.1 Limiting and recycling wastes
4.3. The economic downturn and alternative fuels
4.4 AFR usage in the cement manufacturing process at Lafarge
4.5 Carbon dioxide emissions at Lafarge between 1990 and 2010
4.6 Environmental Impact Assessment of the granted visit to Dunbar Cement Plant
4.6.1 Alternative Fuels used at Lafarge (Dunbar, UK)
4.6.1.1 Tyre Chips

4.6.1.2 Recycled liquid fuel
4.7 Wind energy potential in Dunbar Cement Works
4.7.1 Proposed wind farm for Dunbar Cement Works
4.7.2 Wind resource assessment and wind turbine modelling
4.8 Result and conclusion

Chapter-5 Case Study for Holcim Cement Company worldwide 97-121

5.1. Holcim Cement Operation
5.2 Holcim and Sustainable Development
5.3 Environmental Performance Assessment of Holcim
5.3.1 Limiting and recycling waste
5.3.2 Energy consumption at Holcim
5.3.2.1 Alternative Fuels and Thermal energy mix in cement operations at Holcim
5.3.3 Raw materials and ARM used in the cement making process at Holcim
5.3.4 Carbon Dioxide emissions (1990–2010)
5.3.4.1 Clinker factor (ratio of clinker/cement) and CO_2 emissions from clinker
5.3.4.2 Carbon Dioxide emission following increase in rate of raw material substitution
5.3.4.3 Increasing the thermal energy efficiency of the clinker-making process: specific heat consumption
5.3.4.4 Increasing the proportion of energy from AF (thermal substitution rate)
5.4 Discussion and conclusion

Chapter- 6 Case study for Taiheiyo Cement Corporation Worldwide 122-153

6.1 Introduction
6.2 Energy consumption by the cement industry in Japan
6.3 Recycled municipal waste as alternative fuels and raw materials for cement production
6.4 Taiheiyo Cement Corporation
6.5 Municipal waste recycling systems for cement production at Taiheiyo cement operations
6.5.1 Fly Ash Washing System

6.5.1.1 Bottom Ash Receiving Facility
6.5.2 AK System
6.5.2.1 Manufacturing process of AFR after leaving the AK System
6.6 Environmental performance assessment and opportunities for environmental impact reduction in cement production at Taiheiyo
6.6.1 Limiting and recycling waste
6.6.2 Raw materials input in cement production and usage of ARM
6.6.3 Alternative fuel usage in cement operations at Taiheiyo
6.6.4 Assessment of CO_2 emissions trends at Taiheiyo
6.7 Results of the Environmental Impact Assessment and Environmental Economic Benefit Evaluation for Taiheiyo cement operations

Chapter 7 Comparison (Taiheiyo, Lafarge, Holcim) 154-187

7.1 Introduction
7.2Opportunities for manufacturing cements based on MSWIA in the UK
7.2.1 The eco-cement system potential in the UK in response to Ecocement manufacturing at Taiheiyo Company
7.3 Environmental Performance Indicators
7.3.1 Thermal energy consumption
7.3.2 Waste consumption
7.3.3 Clinker factor
7.3.4 CO_2 emissions: "specific Net CO_2 emissions and Gross CO_2 emissions"
7.4 Results and discussion
7.5 Conclusion

Chapter-8 Conclusion and Recommendations 188-195
8.1 Conclusion
8.2 Recommendations and further work

196-202

Appendices 203-218

Appendix1

Sources of ARM. ECRA Technology papers (2009). WBCSD & IEA Cement Technology

Appendix 2

Energy savings measures and emission reduction (Kg CO_2/tonne)

Appendix 3

Waste Use: Recycling and reuse materials found on superfund sites(either as ARM or AF in process of cement production)

Appendix.4

CO2 emissions

4.1 (Direct CO_2 Emissions from Cement Production: Cement-Based Methodology) according to GHG Protocol Tool [Version: 2.0. June 2005].
4.2 WBCSD Cement Sustainability Initiative: CO_2 Emissions Inventory [GHG Protocol, version2.0]

Appendix .5

Personal Contacts and communications with the cement companies

5.1 Contacts with Taiheiyo
5.2 Contacts with Holcim
5.3 Holcim and Lafarge interviews 'questions

Appendix .6

6.1 Inputs of manufacturing process
6.2 Outputs of CO_2
6.3 Environmental Impact Assessment and the socioeconomic benefit evaluation (2000-2010)
6.4 Results of Environmental performance Assessment for (Taiheiyo, Holcim, Lafarge)

List of figures

Chapter 1 1-11

Figure 1.1 The Sustainability Indicators (SIs) for measuring sustainability progress in cement production along the three dimensions (environmental, social, and economic) of sustainability.

Figure1.2 CO_2 emissions as the research big issue, and the three main levers of generation exemplifying the key issues.

Chapter 2 12-55

Figure 2.1Forthcoming expected cement consumption in the short, medium and long term according to Ocean Shipping Consultants Ltd Report.

Figure 2.2 Global cement consumption trends by region according to CemNet website, showing regional distribution from1997 to 2010.

Figure 2.3 Global cement consumption per capita, 1990–2010.

Figure 2.4 Regional Cement Consumption shares worldwide in 2010.

Figure 2.5 China cement consumption vs rest of world consumption over the period 1998–2010.

Figure 2.6 China average consumption vs rest of world from 2006 to 2010.

Figures 2.7(a. right, b. left) Comparison between top ten cement consuming countries and top ten cement producers in 2010.

Figure 2.8 Comparison between consumption and production of cement in regions of world for 2008.

Figure 2.9 China cement production vs. rest of world cement production

Figure 2.10 Historical trends of cement production over 5 years worldwide, based on www.CemNet.com regions distribution

Figure 2.11 different kinds of cement produced in Europe

Figure 2.12 Simplified process schematic of cement production

Figure 2.13 Calcining reaction for cement making (Dunbar).

Figure 2.14 Portland cement dry and wet manufacturing process

Figure 2.15 Energy requirements per ton of clinker by country including AF.

Figure 2.16 Share of GHG emissions released from cement industry worldwide

Figure 2.17 Absolute gross CO_2 emissions worldwide, 1990–2006 (GNR).

Figure 2.18 Energy recovery from waste burning in cement kiln

Figure 2.19 Schematic Representation of Capture Systems

Figure2.20 Illustrative flow sheet for the process of (post-combustion capture)

Figure 2.21 Illustrative flow sheet for IGCC (pre-combustion capture)

Figure 2.22 Illustrative flow sheet for the process of oxy-fuel (Oxyf), with additional unit operations for carbon capture shown bold

Figure2.23 Schematic diagram of possible CO2 capture and storage system by Intergovernmental Panel on Climate Change

Figure 2.24 Schematic diagram reflects the increasing of CO_2 amount produced in plant with CCS

Figure 2.25 Percentage increase in fuel use per kWh of electricity due to CO2 capture, compared to the same plant without capture

Chapter 3 **56-68**

Figure 3.1 The Triple Bottom Line of Sustainability

Figure 3.2 A sustainable system for manufacture

Chapter 4 **69-96**

Figure 4.1 World map of Lafarge's presence as at December 31, 2010 (Plants and sales offices).

Figure 4.2 Water footprint at Lafarge 2009–2010

Figure 4.3 Water consumption in cement works at Lafarge from 2000 to 2010.

Figure 4.4 Rates of recycled water used in Lafarge cement works.

Figure 4.5 Waste recovery system, by the author.

Figure 4.6 Types of alternative fuel used in cement plants in 2009 and 2010 as % of total alternative fuel use.

Figure 4.7 Improvement Trends of Thermal Energy Mix at Lafarge

Figure 4.8 Trends in CO_2 net emissions from cement production at Lafarge between 1990 and 2010

Figure 4.9 Carbon dioxide efficiency of clinker production at Lafarge in 2010 compared to 1990 levels.

Figure 4.10 Actions to reduce CO_2 emission footprint at each step in Lafarge cement operations, these measures being in response to different actions and factors, not just one single action

Figure 4.11 Levels of absolute CO_2 emission at Lafarge cement operations since 1990

Figure 4.12 Used raw materials and their CO_2 emissions generated into atmosphere.

Figure 4.13 Dunbar cement production for 2008, and total CO_2 emissions into atmosphere: monthly data

Figure 4.14 World wind turbine installed capacity between 1997 and 2009.

Figure 4.15 Wind roses for Edinburgh city and Dunbar location

Figure 4.16 The suggested location for the three Vestas V90 wind turbines at Dunbar cement works.

Chapter 5 **97-121**

Figure 5.1 Development of cement production at Holcim between 1990 and 2010.

Figure 5.2 The Sustainable Development perspectives in Holcim's cement operations.

Figure 5.3 (A) left and 5.3 (B) the production rate of OPC at Holcim

Figure 5.4 Summary of waste definitions.

Figure 5.5 Waste recovery by cement operations at Holcim and benefits of co-combustion of alternative fuels in the cement industry.

Figure 5.6 Improvement of thermal energy mixed to produce one tonne of clinker (1990–2010)

Figure 5.7 the improvement trends of waste utilization as alternative fuels at Holcim (2000, 2011).

Figure 5.8 Improvement trends of thermal energy consumption at Holcim between 1990 and 2010

Figure 5.9 the CO_2 emissions output from ordinary Portland cement and the from cement materials utilized waste as fuel

Figure 5.10 Improvements and changes in ARM usage at Holcim.

Figures 11 (a, b)Siggenthal cement operations laboratory

Figure 5.12 Total CO_2 emissions from cement operations at Holcim from 1990 to 2010.

Figure 5.13 Improvement in carbon efficiency, gross and specific, at Holcim from 1990 to 2010.

Figure 5.14 Development and reduction of clinker/cement ratio from 1990 to 2010

Figure 5.15 Changes in mineral components used in cement produced at Holcim from 1990 to 2010.

Figure 5.16 CO_2 emissions from cement, calcination process, and saving of CO_2 from ARM usage (Kg CO_2/tonne cement).

Figure 5.17 The increasing ratio of thermal energy efficiency (specific heat consumption) in 2010, which is the total thermal energy consumed per tonne of clinker produced, compared to 1990 levels.

Figure 5.18 Improvement trends in thermal energy efficiency from alternative fuels usage from 1990 to 2010.

Figure 5.19 Clarification of the identified indicators and assessment of environmental impacts progress for specific years

Chapter 6 **123-155**

Figure 6.1 Energy requirements per tonne of clinker by country including alternative fuels

Figure 6.2 Japanese CO_2 emission compared to the World (WBCSD, GNR).

Figures 6.3 and 6.4 Energy consumption of Japanese cement industry from fossil fuels, fossil waste and biomass

Figure 6.4 Absolute volume of alternative fossil fuels(Mt/year)

Figure 6.5 Improvement of Thermal Energy Consumption by the Japanese cement industry (MJ/ t cement) 1980–2009 (JCA).

Figure 6.6 Trends in cement production, clinker production, clinker factor, and the improvement of waste consumption in Japan (JCA).

Figure 6.7 Improvement tendency of specific power consumption by the Japanese cement industry (kWh/tonne cement) in 2009 compared to 1980 levels

Figure 6.8 Bottom ash washing process (top) and Figure 6.23 Fly ash washing process (bottom).

Figure 6.9 Process of the Fly Ash Washing System applied by Taiheiyo Cement Company.

Figure 6.10 The magnetic belt separator used in the Bottom ash system.

Figure 6.11 AK System operations at Saitama plant, begun in February 2002 (top), and technology for recycling municipal waste (bottom

Figure 6.12 Specific waste usages at Taiheiyo with two different utilizations, as ARM and AF.

Figure 6.13 Consumption trends of natural raw materials for cement operations at Taiheiyo Cement Company from 2000 to 2010.

Figure 6.14 Development of various types of waste utilized as ARM in Taiheiyo cement operations

Figure 6.15 Trends in total raw materials used including Natural and ARM, and the changes in ratio of ARM to cement production.

Figure 6.16 Consumption trends in AF from Recycled Fuels including Biomass Waste + Fossil waste as a percentage of thermal consumption (percent Waste).

Figure 6.17 Total inputs in the cement manufacturing process for Taiheiyo cement operations

Figure 6.18 Trends in total Gross CO_2 emissions and total Net CO_2 (Kg CO_2/tonne cement) from 1990 to 2010.

Figure 6.19 Total specific CO_2 emissions reductions from the production process, fuels combustion, electricity consumed and cement manufacture.

Figure 6.20 Intensity development of CO_2 emissions released from limestone calcinations.

Figure 6.21 Trends in cement production, clinker production, and clinker factor at Taiheiyo.

Figure 6.22 Trends in CO_2 efficiency released from clinker at Taiheiyo.

Figure 6.23 Trends in the evaluated Environmental Conservation Benefit (2000–2010).

Figure 6.24 Environmental Impact Assessment for cement operations at Taiheiyo.

Chapter 7 **156-187**

Figures 7.1 (a) (b) Comparison of raw materials for Ordinary Portland Cement and Eco-cement

Figure 7.2 The scheduled process flow of Eco-cement production (Taiheiyo.Cement.company 2008)

Figure 7.3 EIA indicators to benchmark performance of Taiheiyo, Holcim, and Lafarge in 2000

Figure 7.4 Environmental performance benchmark in 2007 (Taihciyo, Holcim, Lafarge).

Figure 7.5 Environmental performance benchmark in 2010 (Taiheiyo, Holcim, Lafarge)

Figure 7.6 Total specific energy consumption including electricity consumption + fuels (data collected and analysed from Taiheiyo Sustainability Reports 1990-2010).

Figure 7.7 Trends in specific reductions of energy usage at Taiheiyo from 1990 to 2010.

List of tables

Chapter 1 **1-11**

Table 1.1 the research methodology.

Chapter 2 **12-55**

Table 2.1 Global cement consumption trends for worldwide regions from1997 to 2006.

Table 2.2 Increasing trends of cement consumption worldwide from 1990 to 2010.

Table 2.3 Historical production trends for global cement production from1997 to 2006.

Table 2.4 Main cement types, composition and raw materials needed.

Table 2.5 Chemical composition and weight percentage of Portland clinker and Gypsum

Table 2.6 Oxide composition of Portland cement (Olga Shtepenko, 2006)

Table 2.7 Chemical analysis of cement raw materials.

Table 2.8 Energy requirement of different clinker making

Table 2.9 Energy efficiency and CO_2 emitted from global cement industry

Table 2.10 Proportion of cement industry emission of GHGs

Table 2.11 Global carbon emissions from cement production

Table 2.12 GNR variable in 2006 for the cement industry sector worldwide.

Table 2.13 Non-suitable materials for co-processing and the key reason for exclusion from co-processing.

Table 2.14 The advantage and disadvantage of waste utilization in cement production.

Table 2.15 CO_2 released from cement production in 2005 (IGPCC 2005)

Chapter 3 **13-68**

Table 3.1.a Achievements of CSI members (CO_2 and Climate Protection)

Table 3.1.b Achievements of CSI members (Responsible Use of Fuels and Raw Materials)

Table 3.1.c Achievements of CSI members (Employee Health and Safety)

Table 3.1.d Achievements of CSI members (Emissions Monitoring and Reduction)

Table 3.1.e Achievements of CSI members (Local Impacts on Land and Communities)

Chapter 4 **69-96**

Table 4.1 Types of AF used in cement manufacture at Lafarge worldwide.

Table 4.2 Environmental expense savings according to 1990 levels

Table4.3 Rate of raw materials consumed at Lafarge including the alternative raw materials

Table 4.4 Main Alternative Raw Materials consumed by Lafarge by 2010

Table 4.5 Fuel mix evolution in Lafarge's cement business

Table 4.6 Improvement and progress of specific levers affecting the reduction of CO_2 released by cement manufacture at Lafarge

Table 4.7 Amount of raw materials used and their emissions

Table 4.8 Dunbar cement production and emissions for 2008

Table 4.9 Breakdown of electricity consumption for each single stage of the cement manufacturing process at the Dunbar works.

Table 4.10 Monthly cement production with electricity consumption plus its cost.

Table 4.11 Monthly average wind speed for candidate location.

Table 4.12 Performance of the chosen machines for the site under consideration.

Table 4.13 Economics of wind energy for the chosen machines.

Table 4.14 CO_2 emission saving rate at Lafarge Cement Group over the period 1990–2010.

Table 4.15 Environmental performance assessment of Lafarge Cement Production from 1990 to 2010.

Chapter 5 **97-121**

Table 5.1Types of cement produced by Holcim between 1990 and 2009

Table5.2 Types of waste materials and its usage at Holcim

Table 5.3 Improvement trends of waste recovery at Holcim

Table 5.4 Waste materials utilized in cement operations at Holcim to replace the natural raw materials

Table 5.5 Natural and alternative raw materials used at Holcim through the manufacturing process up to the final cement product.

Table 5.6 CO_2 emission saving and natural resource conservation (1990–2010)

Chapter 6 **122-155**

Table 6.1Treatment of municipal waste in Japan

Table 6.2 Saving in Energy consumed by Japanese cement Industry between (1980-2009)

Table 6.3 Consumption amounts and rates of various wastes materials and by-products at Taiheiyo Cement Corporation.

Table 6.4 Chemical Compound for cement materials at Taiheiyo

Table 6.5 Levers, inventory and impact of the Environmental Performance of cement production.

Table 6.6 Utilization of recycled resources at Kumagaya plant, Tokyo.

Table 6.7 Basic chemical composition of cement produced at Taiheiyo (%)

Table 6.8 Improvement in waste consumption in 2010 compared to 1990 levels

Table 6.9 CO_2 reduction calculation at Taiheiyo

Table 6.10 Environmental Impact Assessment and the socioeconomic benefit evaluation at Taiheiyo (2000-2010)

Chapter 7 **156-187**

Table 7.1 EPI (Environmental performance indicators in 2000)

Table 7.2 EPI (Environmental performance indicators in 2007)

Table 7.3 EPI (Environmental performance indicators in 2010)

Table 7.4 Best Performance Company as determined by using the scoring system

Table 7.5 CO_2 performance at Taiheiyo (2000-2010)

Abbreviations

AF	Alternative Fuels
AFR	Alternative Fuels and Raw Materials
AK	Applied Kiln System
ARM	Alternative raw materials
AUCBM	Arab Union for Cement and Building Materials
BFS	Blast Furnace Slag
CCS	Carbon Capture and Storage
CEMBUREAU	The European Cement Association Based in Brussels
CKD	Cement Kiln Dust
CL	Clinker
CLF	Clinker Factor
CN (CemNet)	International Cement Review
CSI	Cement Sustainability Initiatives
EF	Emission Factor
EI	Energy Isolation
EIA	Environmental Impact Assessment
EPI	Environmental Performance Indicators
ET	Emission Trading
FAW	Fly Ash Washing System
GNR	Getting Number Rights
IEA	International Energy Agency
IFA	Incineration Fly Ash
IPCC	Intergovernmental Panel on Climate Change

JCA	Japanese Cement Association
MSW	Municipal Solid Waste
MSWIA	Municipal Solid Waste Incineration Ash
OPC	Ordinary Portland Cement
PCA	Portland Cement Association
RDF	Recycled Derived Fuel
RLF	Recycled Liquid Fuel
RM	Raw materials
SD	Sustainable Development
SDR	Sustainable Development Report
WBCSD	World Business Council for Sustainable Development
LSF	Lime Saturation Factor
BCA	British Cement Association
EPA	Environmental Protection Agency
MTOE	Million Tonne Oil Equivalent
EWET	European Wind Energy Technology
BWEA	British Wind Energy Association

Glossary of Terms

Absolute gross emissions The total amount of CO_2 emitted from cement production activities.

Absolute net emissions Gross emissions minus credits for indirect savings, such as use of waste as fuel

Alternative Fuels and Raw Materials Inputs to clinker production derived from waste streams contributing energy/or raw material.

Blast furnace slag A proceed waste product of iron production in blast furnace s that is usable as pozzolan

Clinker Factor The percentage of clinker in cement manufacturing produced by decarbonising, sintering, and fast- cooling ground limestone

Composite cement is cement with a fixed percentage of secondary cementitious materials, such as slag and fly ash, replacing the clinker portion of the cement

CKD discarded dust from long dry and wet kiln system de-dusting unites, consisting of partly calcined kiln feed material. The term "CKD" is sometimes used to donate all dust from cement kilns, i.e. also from bypass system.

Gross CO_2 emissions Total direct CO_2 emissions (excluding on site electricity production) originating from fossil carbon.

Direct emissions are emissions from sources that are owned or controlled by the reporting company.

Fly ash By product with binding properties typically produced as a residue from coal fired power plants

Fossil Fuel Non renewable carbon-based fuels traditionally used by the cement, including coal, oil, natural, and oil shale

GHG the greenhouse gases listed in Annex A of the Kyoto Protocol include: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) per fluorocarbons (PFCs), hydro fluorocarbons (HFCs) and sulphur hexafluoride (SF_6).

GNR Getting the Numbers Right" project and CSI's global cement database covering over 800 plants around the world belonging to CSI member companies.

Gross Emissions are the total direct CO_2 emissions from the cement plant or company including CO_2 from fossil wastes (but excluding CO_2 from biomass wastes)

IPCC The intergovernmental Panel on Climate Change is an international body of scientists. Its role is assessing the scientific, technical and socio-economic information relevant to the understanding of risk of human-induced climate change (www.ipcc.ch).

Indirect emissions are emissions that result as a consequence of activities of the reporting company but occur at sources owned or controlled by another company.

Kiln feed Raw materials often processed as raw meal, which are fed to a pre- heater or directly into kiln system.

MJ mega joule; a unit of work or energy

Specific net emissions The net CO_2 emissions per tonne of cement

Specific gross emissions The gross amount of CO_2 emitted per tonne of cement

Secondary Cementitious materials Industrial by-products, such as blast furnace slag and fly ash that have cementitious properties and are used to substitute clinker in cement.

Thermal energy equivalent mass of a substance whose thermal energy content equals that of a chosen standard material

Wind farm a number of electricity generating windmills sited in the same area.

Chapter 1

Introduction

1.1 Introduction

Sustainable Development is an imperative requirement for the well-being of the planet, continual growth, and human development. Cement is one of the most extensively used construction materials in the world. But the amount of CO_2 which has been produced by calcinations of limestone and combustion of fuels make the cement industry one of the top sources, among manufacturing industries, of carbon dioxide emissions, which are considered the main culprit in climate change.

The production of one tonne of Portland cement at Lafarge generated about one tonne of CO_2 in 1990, reduced to 0.780 tonne in 2010.

The environmental issues associated with CO_2 emission, in addition to the large amounts of energy and raw material consumed in cement manufacture, played a principal role in concern for sustainable development within the cement industry during this century, leading to the creation of the Cement Sustainability Initiative (CSI), which operates under the World Business Council for Sustainable Development. The WBCSD is a group of cement companies, including Lafarge, Holcim, and Taiheiyo, who have initiated a project on sustainable cement. Their aim was to determine how the cement industry can become sustainable. In signing the Agenda for Action, the companies have addressed six critical issues for the cement industry:

- Climate protection and CO_2 management;
- Responsible use of fuels and materials;
- Employee health and safety;
- Emissions monitoring and reporting;
- Local impacts on land and communities;
- Reporting and communications.

This study and the associated data analysis will further examine the response to the WBCSD initiatives, as seen in the environmental performances of Lafarge, Holcim, and Taiheiyo cement companies, with special reference to the CO_2 emissions reduction options from 1990 to 2010.

The main objective of this study is to focus on the development of new opportunities for producing cement with less CO_2 emissions and less consumption of natural resources. The core of the thesis is a descriptive, analytical, and evaluative study of the impact of environmental performance indicators on the rapid development of cement production technologies over the last twenty years, using the benchmarking tool to identify the best environmental performance worldwide.

The following preliminary statement defines the main hypothesis to be tested:

How Sustainable is Cement Production with Special Reference to its Environmental Impact and CO_2 Emissions Reduction?

This key hypothesis highlights the development of the cement manufacturing process in order to enable designers and practitioners to measure and assess the level of sustainability of the cement industry during its manufacturing process, with particular reference to the options for CO_2 emissions reduction.

Because of the predominant use of carbon-intensive fuels, such as coal in clinker making, the cement industry is a major source of CO_2 emissions. Besides consuming energy, the clinker-making process emits CO_2 during calcining (Michael Taylor et al 2006). Because of these two emission sources, in addition to the emissions from electricity production, the cement industry is a major source of carbon emissions and deserves attention in the assessment of carbon emission-reduction options. The emission mitigation options will be reviewed, including energy efficiency improvement, new processes, a shift to low carbon fuels, application of waste fuels, increased use of additives in cement making and, eventually, alternative cements and removal of CO_2 from flue gases in clinker kilns.

The environmental impact analysis, performed within clearly defined and consistently applied boundaries, will provide a value for the impact of cement production on the environment. The calculation of this value will be based on the material, resource and energy inputs and the material, waste and pollution outputs. The value calculated will be used as a benchmark figure against which to compare the sustainable technology values calculated. The technologies will be analysed in terms of their environmental impact during production.

1.2 Sustainability Indicators (SIs) and Environmental Performance Indicators (EPIs)

Indicators have become widely acknowledged as tools for measuring the performance of building materials. Depending on what is being measured, indicators have been used within different frameworks(Guy and Kibert 1998).

Sustainability Indicators (SIs)

Sustainable Development in the new millennium has been recognized along three overlapping dimensions: Social, Economic, and Environmental. The main focus is on establishing a list of SIs within the three dimensions of sustainability by the first decade of the new millennium, to enable cement experts and companies to understand the wider potential of the sustainability dimensions and then to apply them in cement operations. Furthermore, sustainable indicators embrace more than environmental performance; they have social and economic dimensions extending to all factors of human activity (e.g. industry, transportation, buildings, etc.) (Cole 1999). "Sustainable development is an evolving process that improves the economy, the society and the environment for the benefit of current and future generations" (John Drexhage 2010). The frontiers of sustainability are much broader, requiring a number of SIs. Relative indicators are classified in three groups depending on data availability and relation of the indicators to the core of the study (cement operations of different companies).

Environmental Performance Indicators (EPIs)

Sustainable development for cement production involves increased concentration on the real value of the natural and built environments (Mackley and Milonas 2001). Environmental indicators include three main categories of perspectives related to human society, as follows (Mackley and Milonas 2001):

1. The natural resources which provide various kinds of raw materials and fuels as required for the cement industry.
2. Substantial economic benefit, especially since the environment acts as a sink to receive and recycle the waste products of economic activities.
3. Recognition that the environment supports life on earth

Figure 1.1 explains the sustainability indicators set by this research to promote sustainable cement production, with special emphasis on the environmental aspect, and to design a model for lowering this impact.

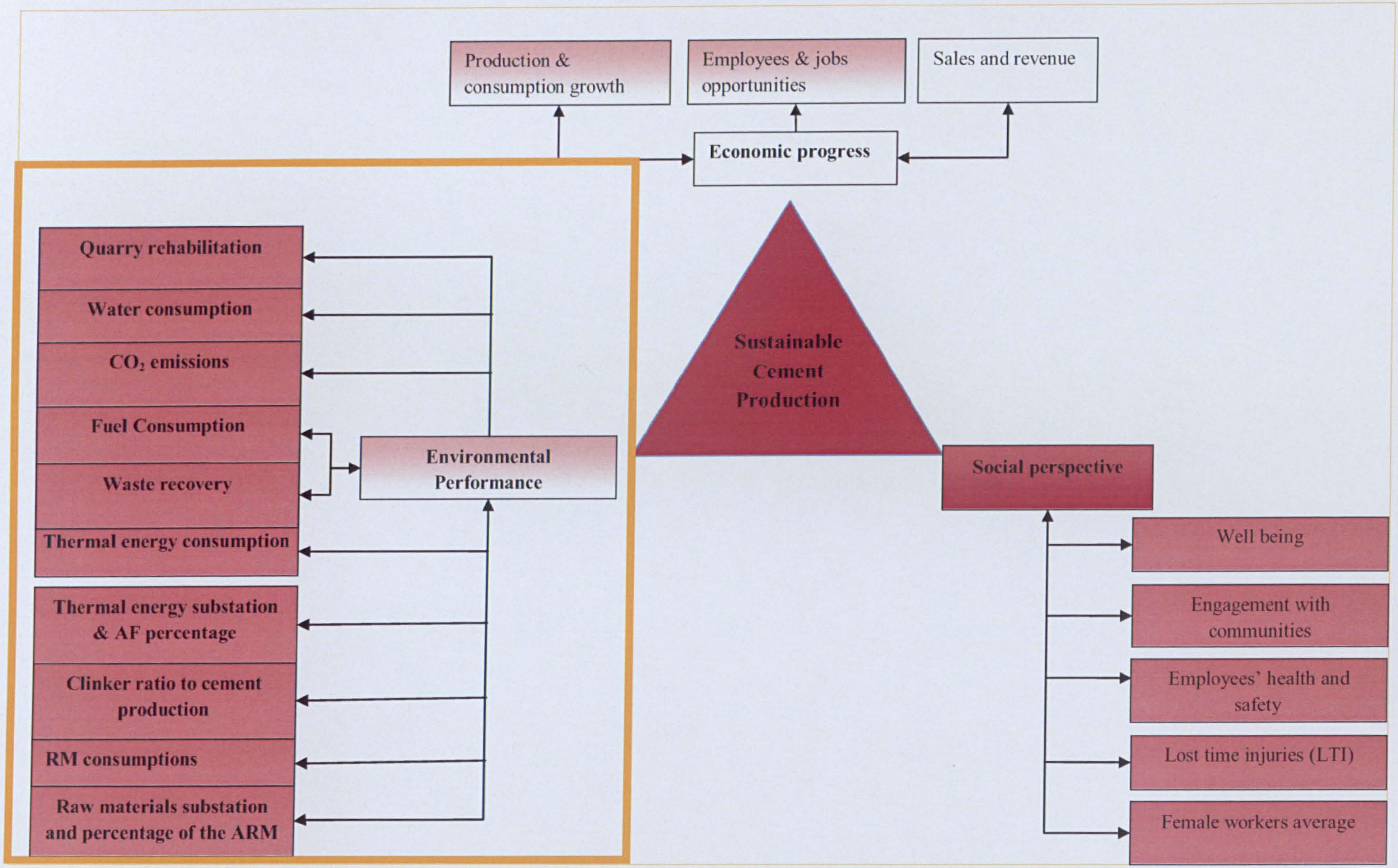


Figure 1.1 The Sustainability Indicators (SIs) for measuring sustainability progress in cement production along the three dimensions (environmental, social, and economic) of sustainability.

1.3 Research Aim and Objectives, and Scope of Activities

1.3.1 Research Aim and Objectives

This research has identified principal objectives the achievement of which will contribute to the sustainable development of cement, as follows:

1. Reduce the consumption of natural resources per tonne of cement manufactured.
2. Reduce the amount of cement process waste residues disposed of per tonne of cement.
3. Reduce emissions of greenhouse gases per tonne of cement manufactured.
4. Optimize the sustainable use of wastes from other industries or sources.
5. Develop site restoration plans and biodiversity action plans.
6. Improve transparency, understanding and engagement between the industry and other stakeholders.
7. Protect the health of workers as a well-being factor alongside those of the environment and local communities.

Figure 1.2 clarifies the major issue in this research (lowering the CO_2 emission level) and the key concerns or specific objectives. Hence, achieving these objectives will support attainment of the main aim of the research.

1.3.2 Scope of Activities Covered by the Plan

The scope of the plan included the following areas:

- Review cement sustainability commitment, especially that of the WBCSD.
- Set plan to contact cement companies who are already participating and are members of the WBCSD.
- Visit cement operations sites – Lafarge, Holcim, Taiheiyo – to set sustainability indicators and establish specific indicators for measuring the environmental impact of cement production in each case.
- Use these indicators to benchmark the different performances of cement companies.
- Identify the best performance cement company especially in terms of its environmental footprint and CO_2 emissions released.
- Examine the inputs of natural resources and alternatives used to produce cement, including both raw materials (quarrying and grinding) and energy requirements.

- Examine clinker burning and cement finishing.
- Observe innovative technologies employed for cement making.
- Describe the outputs of the production process with special reference to CO_2 emission, which is the principal concern of this research.

However, the focus will be on the key impacts that are controlled directly by the cement industry. This research will seek to gauge in greater depth the main issues that are not currently controlled. Figure 1.2 below clarifies the main research focus and key issues. Tackling these key issues will lead to reduction in CO_2 released, through achievement of the main objectives:

1. Energy efficiency.
2. Use of alternative fuels and biomass.
3. Reducing limestone, replacement of natural raw materials and clinker substitution.

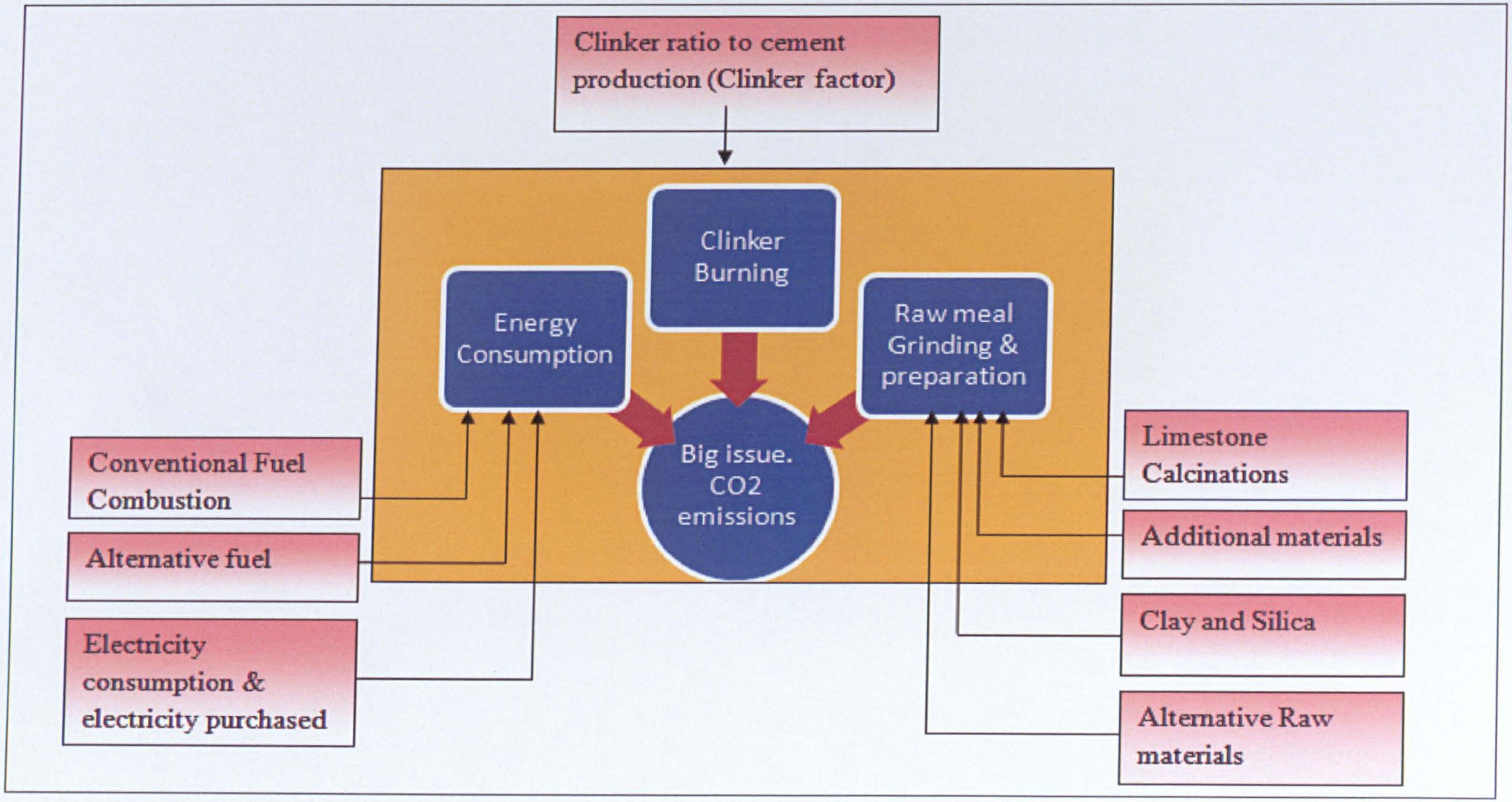


Figure1.2 CO_2 emissions as the research big issue and the three main levers of generation exemplifying the key issues

1.4 Thesis Outline

This thesis consists of eight chapters, as follows:

Chapter 1 This chapter introduces the context and theoretical background of the research, presenting its aim and main objectives, the main hypothesis, and the methodology and tools employed to assess the environmental impact of cement production in view of the importance of reducing CO_2 emissions to protect the planet from climate change.

Chapter 2 This chapter presents the definitions and theories of sustainability, explains the different aspects of Sustainable Development, and reviews the interconnection between cement production and sustainability and its relevance to environmental protection, economic progress and social development. An outline of global cement production and consumption is presented, including details of the world's top ten producers and consumers. The process of cement manufacturing, its development, and its different applicable technologies are reviewed. In addition, this chapter sheds light on the inputs from raw material and energy requirements and on the theoretical calculation of the outputs in terms of CO_2 emissions released at each step of the cement production process.

Chapter 3 In this chapter, the commitments made by the Cement Sustainability Initiative (CSI), operating under the World Business Council for Sustainable Development (WBCSD), are presented. The chapter defines the WBCSD sustainability indicators and explains their importance in shaping this study's specific indicators for measuring environmental impacts and assessing the footprint of CO_2 emissions. It also discusses the research tools, which will depend on the analysis of qualitative and quantitative data, as shown below (Table 1.1).

Table1.1 The research methodology.

Sampling methodology in accordance with the WBCSD Initiatives
Process for selecting and collecting data

Qualitative	Quantitative
Know and evaluate the environmental impact of cement production with particular reference to CO_2 emissions by employing specific environmental impact indicators	Measure the specific Net and Gross CO_2 emissions released throughout the process of cement manufacturing from the energy consumed and the calcination process
Benchmark private data and information collected within site operations	Collect and analyze public information contained in Sustainable Development reports published over 20 years
Tool: Documents and annual reports	Tool: Excel sheet

Chapter 4 This chapter provides the context of the case study of the Lafarge Company and gives an overview of the manufacturing process followed by Lafarge. The case study assesses the environmental impact of cement operations at Lafarge over the last twenty years from 1990 to 2010. The assessment was conducted by identifying the inputs required by the process, including the specific natural raw materials (limestone, clay, and sand) consumed, energy burned, and the alternative raw materials and energy obtained from waste materials and by-products. Great attention was paid to outputs of the manufacturing process, including the clinker produced, to identify the clinker factor per tonne of cement and the specific Net and Gross CO_2 emissions. A detailed analysis was carried out with reference to the three different dimensions (environmental, social, and economic) of the matrix. This chapter also contains a case study of the Dunbar cement plant in Scotland, which is one of Lafarge's cement operation sites, to which the researcher was granted a visit.

Chapter 5 Here the research's second case study, of Holcim Company, is presented. For the purpose of the study, a visit to Siggenthal cement operations in Zurich was allowed. This chapter highlights the manufacturing process and waste utilized therein, focusing on the pre-processing and co-processing systems employed by Holcim. The research assesses the company's performance, especially its environmental performance and impact trends over the twenty years from 1990 to 2010. Then the chapter measures the levels of environmental perspective over the same period in terms of the sustainable development dimensions.

Chapter 6 This chapter discusses cement production in Japan, and in particular Taiheiyo Cement Company. The chapter explains the usage of recycled waste as alternative fuel in Japan and Taiheiyo. The company has been using alternative fuels for nearly a decade and accepts a very wide variety of materials, including shredded pachinko machines (pachinko is a kind of Japanese vertical pinball). The company also uses an ash-washing process to remove chlorides from municipal incinerator bottom ash, so that it can be used as a raw material in cement manufacture.

Chapter 7 This chapter presents the outcome of the research by comparing the performances of the three case studies and interpreting the aggregated results obtained from Chapters 4, 5, and 6. The benchmark illustrates the results obtained by applying EPIs at specific same identified years, to provide comparisons through the use of dimensional diagrams (radar diagrams). The final benchmarked results are linked together to create a scoring system and hence to determine which company has the best environmental performance and lowest environmental impact. This will help to design and plan future cement process initiatives, on the basis of the best performance within the context of cement production. The chapter focuses on the results obtained from the environmental impact assessment and from benchmarking the performance of these companies. Development and changes in the same designated years are explored and discussed.

Chapter 8 This part aims at identifying some important factors related to the scope of the research, with particular reference to newly developed procedures for lowering CO_2 emissions from cement production. General conclusions are drawn as to the achievement of more environmentally sustainable patterns of cement production. In addition, specific environmental improvement guidelines, using the selected case studies, are provided. This chapter identifies the generic and specific procedures for assessing the environmental footprint and outlines the original contribution made towards lowering the amount of CO_2 released.

Chapter 2

Literature Review

2.1 Introduction

In 2005, cement CO_2 emission accounted for 1.8 Gt. 60% of CO_2 emissions (F. M. Lea 2006), the result of chemical reactions in producing clinker, the main component of cement. These reactions are called calcinations or decarbonation of limestone. Therefore, according to the International Energy Agency (IEA 2007), the use of substitutes for the raw materials of clinker was an option that sufficed to reduce CO_2 emissions by about 240 Mt a year. In addition, 40% is emitted by the burning of carbon-intensive fuels such as coal in the clinker-making process. This ratio includes the CO_2 emissions from electricity production. In terms of CO_2 emissions, according to the IEA report in 2003, the intensity of CO_2 emission from cement production across the world ranged from 0.65 to 0.92 tonne CO_2/tonne cement with weight accounting for 0.83 tonne of CO_2/tonne cement.

However, this research will review the emission mitigation options, including technologies for energy efficiency improvement, a shift to low carbon fuels, application of waste fuels, increased use of additives in cement making, and eventually, alternative cements and CO_2 removal from flue gases in clinker kilns.

The environmental performance assessment of the cement manufacturing process, with clearly defined and consistently applied boundaries, will provide a value for the impact of PC upon the environment. The value will be calculated on the basis of the raw materials, ARM, resources and energy inputs, and waste and pollution outputs. The calculated values will be used as benchmark figures, against which the calculated sustainable technology values will be measured. The technologies will be analysed in terms of their environmental impact during production; no process beyond this point will be considered.

2.2 Review of cement consumption worldwide

It is forecast that world consumption of cement will continue to increase throughout the next 15 years, bringing the annual volume from 2380 Mt in 2005 to around 3800 Mt by 2015, and 4250 Mt by 2020, representing overall forward expansion of approximately 56%, according to a detailed new report published by the UK-based independent market consultants Ocean Shipping Consultants Ltd (Steve Hanrahan 2006).

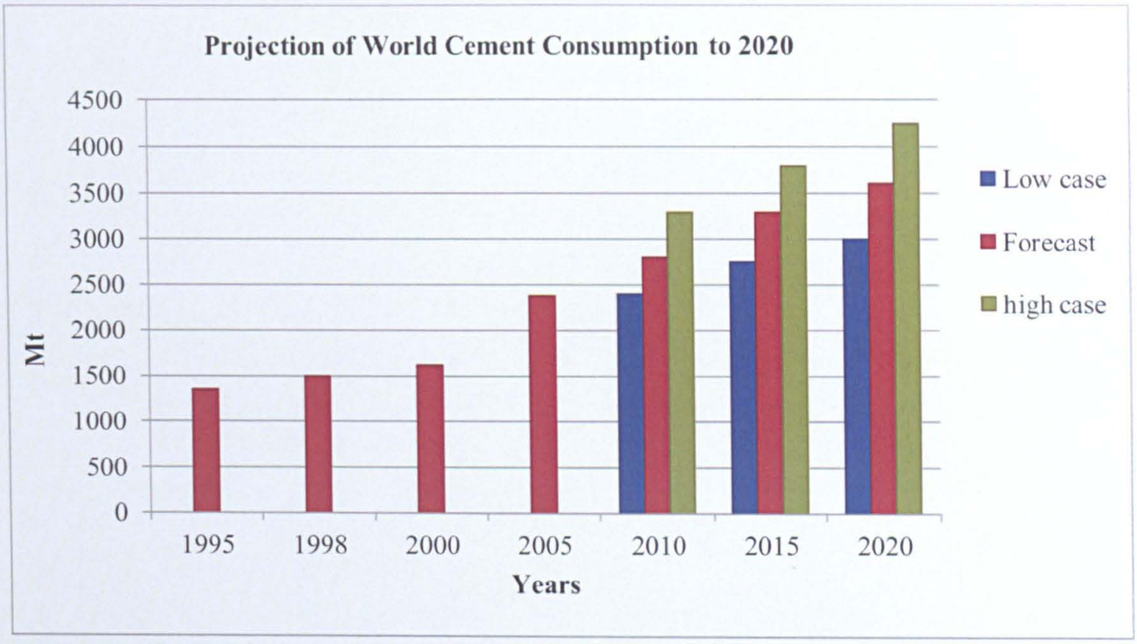


Figure 2.1 Forthcoming expected cement consumption in the short, medium and long term, according to Ocean Shipping Consultants Ltd Report.

Further scenarios have been suggested by Ocean Shipping Consultants Ltd (Steve Hanrahan 2006):

- In the Low Case, the world cement consumption aggregate is predicted to grow only slightly in the short term, to be followed by more substantial growth thereafter. The expected global consumption will be over 2440 Mt by 2010, and 2995 Mt by 2020, with future demand exceeding 31%.
- In the High Case, the expected annual average will expand to a greater extent in the short and medium terms, to start decreasing later. In the long term, this is projected to reach a level of around 3075 Mt by 2010 and 4420 Mt by 2020, with an approximate overall average of 85% (Figure 2.1). However, the anticipated high case of the projection in 2005 has matched the real value of world cement consumption in 2010.

Accordingly table 2.1 shows the global cement consumption trends for worldwide regions according to data collected from CemNet website, showing regional distribution from1997 to 2010.

Table2.1 Global cement consumption (Mt)

Countries	**2010**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**
Middle East	165	88	79	70	69	57	54.6	50	49	45	46
Northern Africa	132	66	61	54	56	54	52.4	50	50	45	43
Southern Africa	33	54	49	45	40	39	35.0	32	32	30	27
Central Asia	264	46	48	39	37	33	28.1	25	24	22	21
South Asia	165	186	166	149	142	133	108.8	125	114	100	89
North Asia	1976	1455	1311	1231	1110	966	851.8	792	780	740	776
Australasia	0	10.3	10.2	9.9	5	5	8.5	9	9	8	8
E. Europe	98.82	96.1	88.3	80.4	74	69	63.1	65	61	58	54
C. Europe	32.94	61.4	55.9	49.9	41	43	48.6	46	49	46	46
W. Europe	231	223	218	215	203	203	199	199	194	185	174
North & South America	198	137.2	136	130	124	119	125	124	117	111	99
Central America	0	54	51	53	50	48	43	41	40	36	34

Figures 2.2 and 2.3 show cement consumption in worldwide regions according to the regional distribution found on www.cemnet.com.

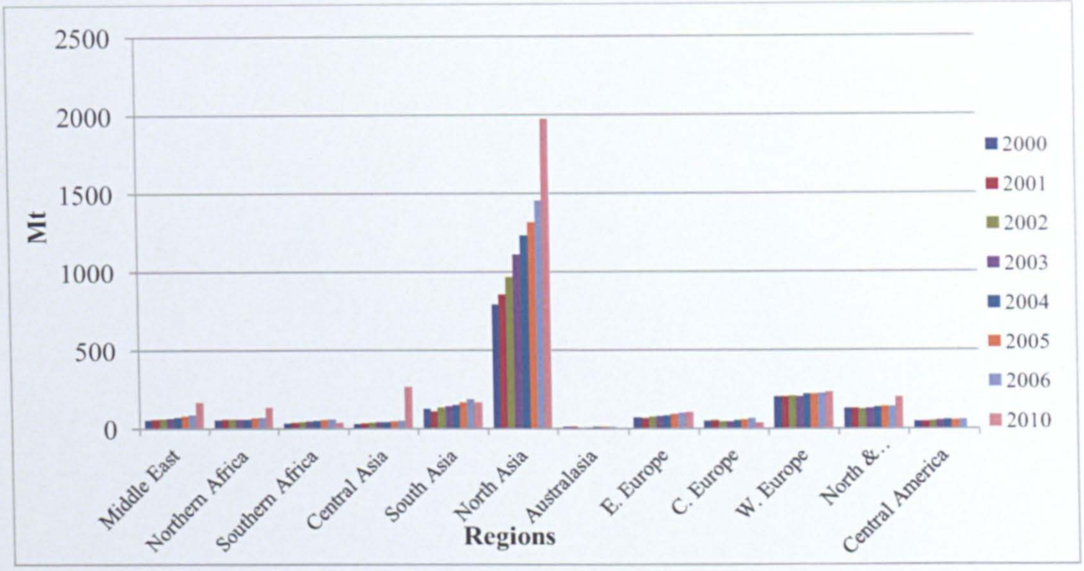


Figure 2.2 Global cement consumption trends by region according to www.CemNet.com showing regional distribution from1997 to 2010.

However, the worldwide cement market enjoyed exceptional growth in 2006 with an annual growth rate of 9.9%. But the construction market weakened cement demand growth in 2007, with a subsequent market growth of just 3.4% in 2008. In normal returns, cement consumption rose from 2.568 Mt, accounting for 3917 t/capita, in 2006, to 3.294 Mt, accounting for 4728 t/capita, in 2010 (Figure 2.3 and Table 2.2; data collected and analyzed from CemNet website).

Figure 2.3 Global cement consumption per capita (Kg/ per capita), 1990–2010.

Table 2.2 Cement consumption is increasing worldwide from 1990 to 2010.

Year	Increscent trends of Global Cement Consumption (Mt)
1990	0.81
2000	1.11
2006	2.57
2007	2.76
2008	2.84
2009	2.99
2010	3.29

However, by looking at the market in regional terms; North Asia, which includes China and Japan, accounts for 60% of global consumption, i.e.1967 Mt in 2010. This compares favourably to the area's 44% share recorded in the decade to 1998. Consumption levels in the Indian Sub-Continent account for 8% of global consumption or 263 Mt. The Middle East, Eastern Europe and Central America also show their share of global demand expanding over the last decade. Consumption in Western Europe was recorded as 230 Mt in 2010, making it the second largest cement consumer in Europe, accounting for 7% of global cement consumption in 2008. North America's share of the world market was 3% in 2010. But South America recorded a lower market share of 3% in 2010 (98.82 Mt) compared to 1998 (110.51Mt).

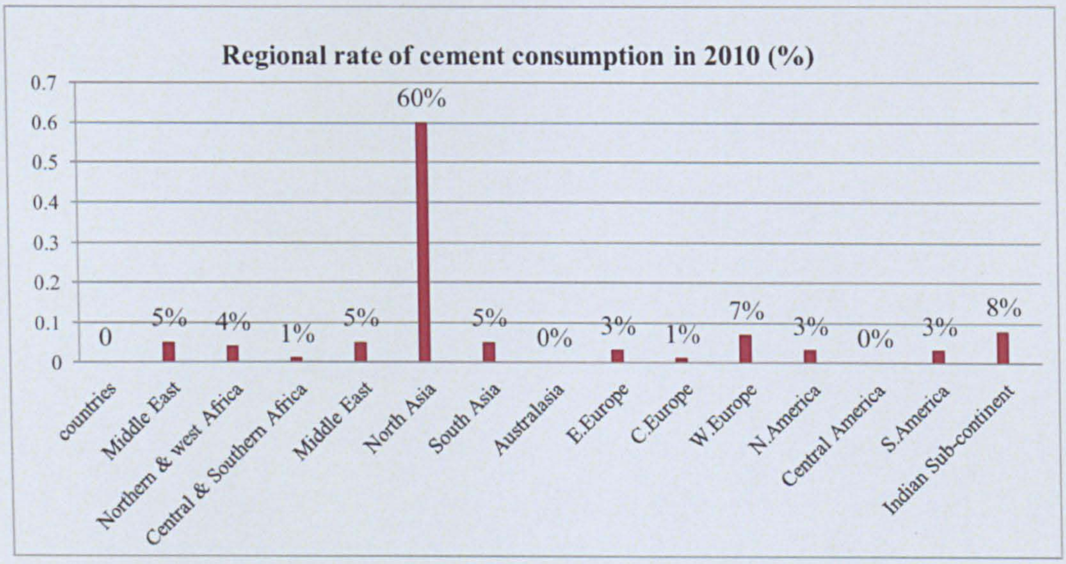


Figure 2.4 Regional Cement Consumption shares worldwide in 2010.
http://www.cemnet.com/publications/GlobalCementReport/world-cement-overview/player.html

In China, cement consumption growth has increased dramatically over the last decades; it rose from 511 Mt in 1998 to 1390 Mt in 2008 and 1851 Mt in 2010, compounding a growth of 10.5% over the period from 1998 to 2010. China's cement consumption now accounts for 49% of global consumption compared to 34% in 1998. Meanwhile, consumption growth in the rest of world was recorded at 4% over this decade (Figure 2.5).

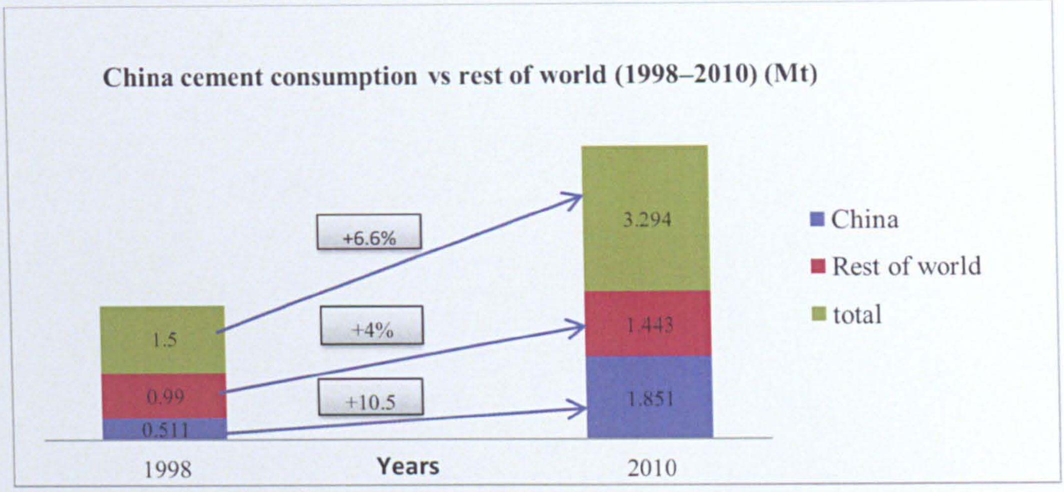


Figure 2.5 China cement consumption vs. rest of world consumption over the period 1998–2010.

In the years between 2006 and 2008, China's annual growth slowed from 13.3% in 2006 to just 5.3% in 2008. Perhaps this is a long-term indication that Chinese cement consumption will be more restrained in upcoming years, reflecting the impact of the financial crisis. Meanwhile, growth in the rest of world declined from 5.5% in 2006 and 2007 to just 1.7% in 2008, to increase in 2010, reaching 1443 Mt (Figure 2.6).

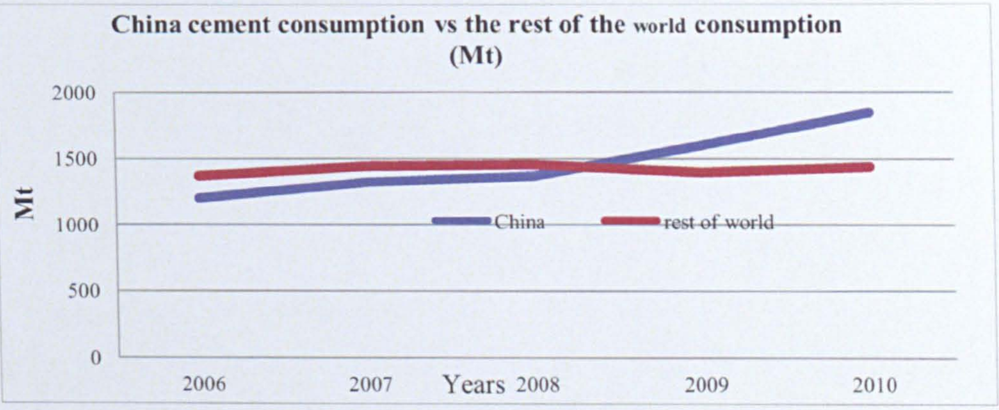
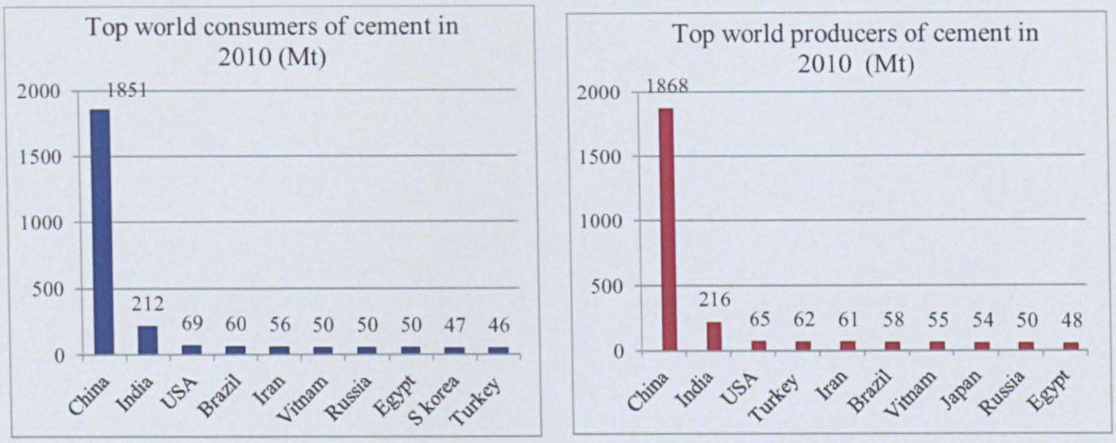


Figure 2.6 China average consumption vs rest of world from 2006 to 2010.

The second of the top ten consumer countries, excluding China, is India, which maintains its second place ranking with demand reaching 180 Mt, up to 9% in 2008, going down in 2010 to reach 8% (212 Mt), thus remaining the second biggest consumer of the top ten. The USA remains in third place despite a 15% drop in demand resulting from the financial crisis and recession, which depressed demand to 69 Mt in 2010. Brazil, on the other hand, as a developed nation, recorded excellent growth in 2008 up to 13%, with an annual growth reaching 51Mt in 2008 and 60 Mt in 2010, to consume around 238 Kg per capita. Next comes Iran, with demand rising from 44 Mt in 2008 to 56 Mt in 2010.



Figures 2.7)(a. left), (b. right) Comparison between top ten cement consuming countries and top ten cement producers in 2010.

The 2005 cement production and consumption report recorded 2283 Mt, representing an expansion of approximately 5.75% (124 Mt) on the previous year and continuing the annual increase, with year-on-year growth since the 1970s, going up to 2825 in 2008.

At the global level, 5-year expansion is expected to approximate 19.75% in 2005–2010, declining to 14.5% in the next half-decade and 13.75% in 2015–20. Above-average growth is anticipated for SE Asia and SW Asia in each of the half decades, with growth approximating 29%, 23.5% and 19.25% respectively for the former. Cement demand in Africa is also expected to be above average in each period, with half-decade performance of over 21% growth for 2005–10, slowing to 13.8% in 2015–20.

2. 3 Review of cement production across the world

Global cement production grew from 1518 Mt in 1997 to 1703 Mt in 2008 at an average annual rate of 1.6% (CemNet.com). Cement production and consumption is cyclical, concurrent with business cycles. Historical production trends for the world regions are provided in Figures 2.7. (a) and (b) show production and consumption trends for the world countries in 2010.

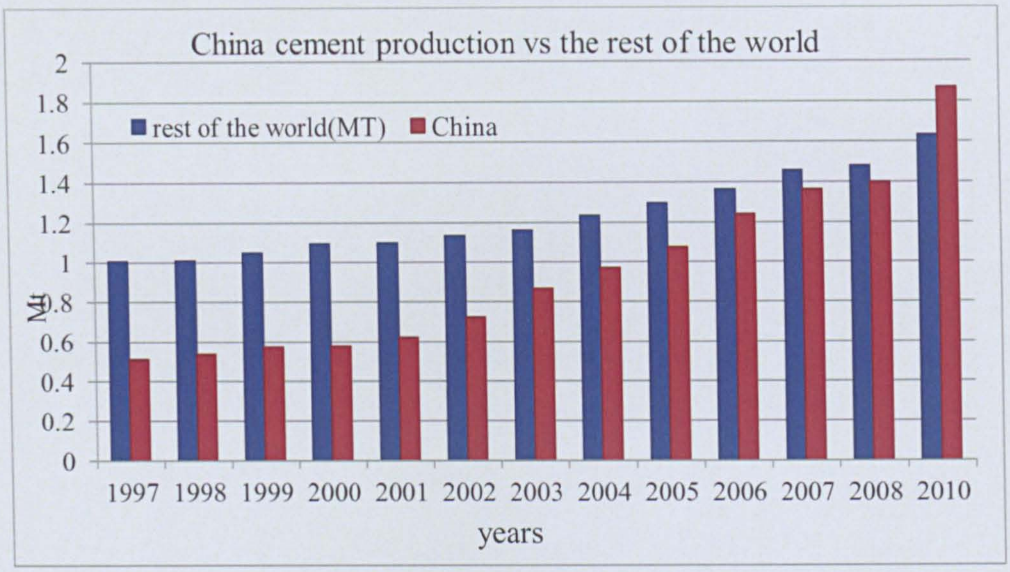


Figure 2.9 China cement production vs. rest of world cement production

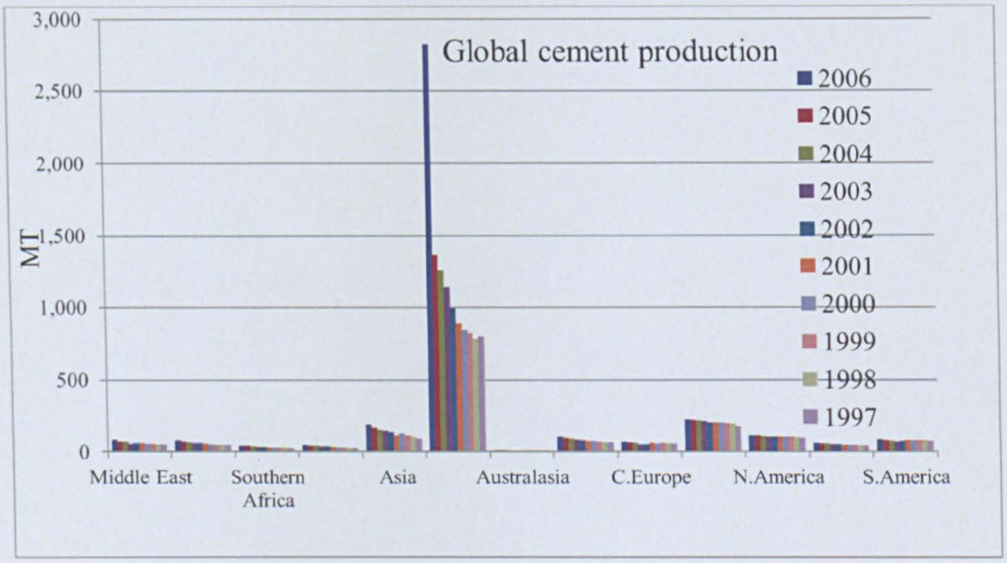


Figure 2.10 Historical trends of cement production over 5 years worldwide, based on www.CemNet.com regions distribution

According to data from the Global Cement Report of 2008, the world accounts for 220 integrated production facilities were up from 1800 Mt recorded in 2006.The number of dedicated grinding facilities was recorded as 380; the total normal cement capacity for additional facilities is estimated at 2770 Mt. China continued to hold significant capacity in 2008 with 800 modern facilities and a capacity of 850 Mt, total production facilities in China comprising 5000 factories in 2008.

In 2008, global cement production was estimated at 2881Mt; the geographically abundant limestone was the most important raw material, and the key role of cement in construction led to its widespread production (Bye 1983). But the level of production is also related to cement's low price and high density (www.CemNet.com).

2.3 Cement properties: composition

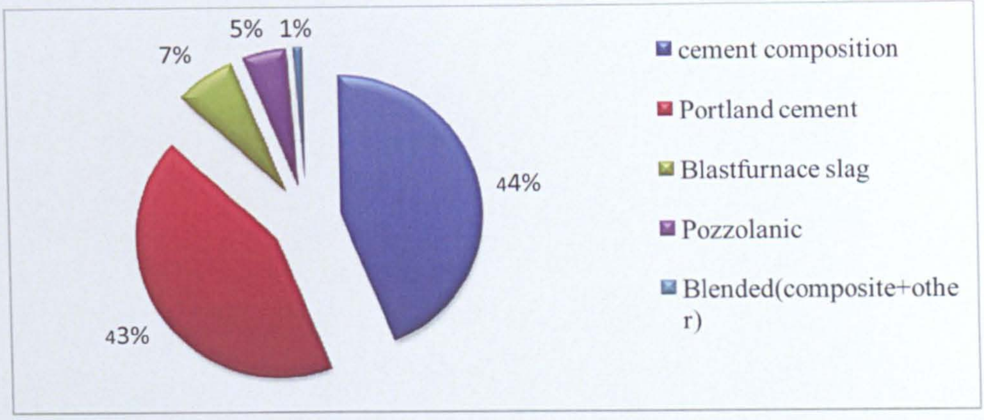


Figure 2.11 different kinds of cement produced in Europe

Cement is an inorganic, non-metallic substance with hydraulic binding properties, which binds solid bodies (aggregate) by hardening from a plastic state. The strength of the cement is retained after being mixed with water and hardening. However, the use of different calcium resources and different additives to regulate properties leads to varied types of cement (G.C.Bye 1999). An overview of significant types of cement is presented in Table 2.4.

Table 2.4 Main cement types, composition and raw materials needed (Ernst Worrell 2001)

Main cement types	Composition	Remarks
Portland*	95%clinker 5% gypsum	Gypsum improves workability of cement
Portland slag	60% Clinker	
Portland Pozzolana	40% slag, Pozzolana, fly ash	-
Portland Flyash	75% clinker, 25% Fly Ash	-
Iron Portland		
Blast Furnace slag	20%-65% clinker 35%-80%blast furnace slag	Only granulated slag can be used, not air cooled
Pozzolanic	60% clinker 40% Pozzolana	Important in countries with volcanic materials
Masonry	Mixture of clinker and ground limestone	Binder for brick work

Portland cement is made up of four main compounds: Tricalcium Silicate, Dicalcium Silicate, Tricalcium Aluminate, and Tetra-Calcium Aluminoferrite (Table 2.5).

Table 2.5 Chemical composition and weight percentage of Portland clinker and Gypsum (G.C.Bye 1999).

Portland Cement Compound	Weight percentage	Chemical Formula	Shorthand notation
Tricalcium Silicate(Alite)	50%	$3CaO\ SiO_2$	C3S
Tricalcium Aluminate(Aluminate)	10%	$3CaO\ Al2O_3$	C3A
Dicalcium Silicate(Belite)	25%	$2\ CaO\ SiO_2$	C2S
Tetra-calcium Aluminoferrite(Ferrite)	10%	$4CaO\ Al_2O_3\ Fe_2O_3$	C4AF
Gypsum	5%	$CaSO_4\ _2H_2O$	CSH2

These components of Portland cement react with water, and the water to cement ratio plays a key role in cement strength. High strength with low workability will result from cement/low water, and low strength with good workability will result from cement/high water (Wikipedia 2011). However, the exact composition of cement determines its properties (e.g. sulphate resistance, alkali content, heat of hydration), whereas fineness is an important parameter in the development of strength and setting rate.

But the most important type of cement product is Blast furnace slag, a combination of iron ore and limestone. The proportion of slag to iron ranges from 0.3 to 1.0 ton of slag per ton of iron. The essential components of slag are the same oxides found in Portland cement, namely lime, silica and alumina, but their proportions differ (G.C.Bye 1999).

The raw materials used to produce cement are a mixture of minerals which look like either powder (in dry process) or slurry (in wet process). Table 2.6 shows these minerals including Calcium Oxide, Silicon Oxide, Aluminium Oxide, Ferric Oxide, and Magnesium Oxide (Wikipedia 2011).

Table 2.6 Typical compositions of the cement minerals as found in Portland cement clinker and cement. The numbers in parentheses are the values for the pure minerals. All values are wt%(Shtepenko, Hills et al. 2006), (Siddiqi 2004).

Symbol (shorthand notation)	Constituent (%)			
	CaO	SiO_2	$Al2O_3$	Fe_2O_3
C2S	63.9	33.9	0.12	0.11
C3S	73.68	26.31	0	0
C3A	62.26	0	37.73	0
C4AF	46.15	0	20.98	32.86

According to Frederick and Bye, the clinker of Portland cement is prepared by burning a mix of raw materials consist of: Calcium carbonate (limestone or chalk), and Aluminosilicate (clay or shale) (table 2.7), then grinding the product with approximately 5% gypsum to produce cement (G.C.Bye 1999), (F. M. Lea 2006).Thus, Grinding and burning ($CaCO3$+ $Al2SiO2$) at 1450° → Clinker → Adding gypsum by 3-5%→ Cooling and Grinding → Cement.

Table 2.7 shows the main substances used to make cement and a form of shorthand known as the cement chemist's shorthand notation (Symbol), which is used to simplify cement formulate. These symbols are single letters replace the usual oxide formulates of Portland cement.

Table 2.7 Typical Chemical analysis and composition of cement raw materials, (G.C.Bye 1999)

Oxide formula	**Shorthand notation(symbol)**	**Chalk (%)**	**Clay (%)**	**Lime (%)**	**Ash (%)**	**Clinker made from (Typical raw mix)**
SiO_2	S	2.5	50	84	48	14.3
Al_2O_3	A	0.5	22	6	29	3.03
Fe_2O_3	F	0.2	9	3	10	1.11
$CaCO_3$	C	97.6		94.1		79.3

2.5 Cement production: description of manufacturing process

Cement making consists of three main steps (Figure 2.12): raw materials preparation (quarrying), making clinker in kiln (burning), and cement making (finishing). Raw materials preparation and finishing to make cement are the chief electricity-consuming processes, whilst burning in the kiln to produce clinker requires most of the fuel consumed in a typical cement plant. Therefore, clinker production is the most energy-intensive production step, responsible for about 70%–80% of the total energy consumed (Nathan Martin 1999). Raw materials preparation and final grinding are electricity-intensive production steps. Energy consumption by the cement industry is estimated at 2% of the global primary energy consumption (Nathan Martin 1999), or 5% of the total global industrial energy consumption. Energy consumed in cement production is one of the crucial potential sources of CO_2 emissions. However, the figure below gives a simplified view of the cement making process.

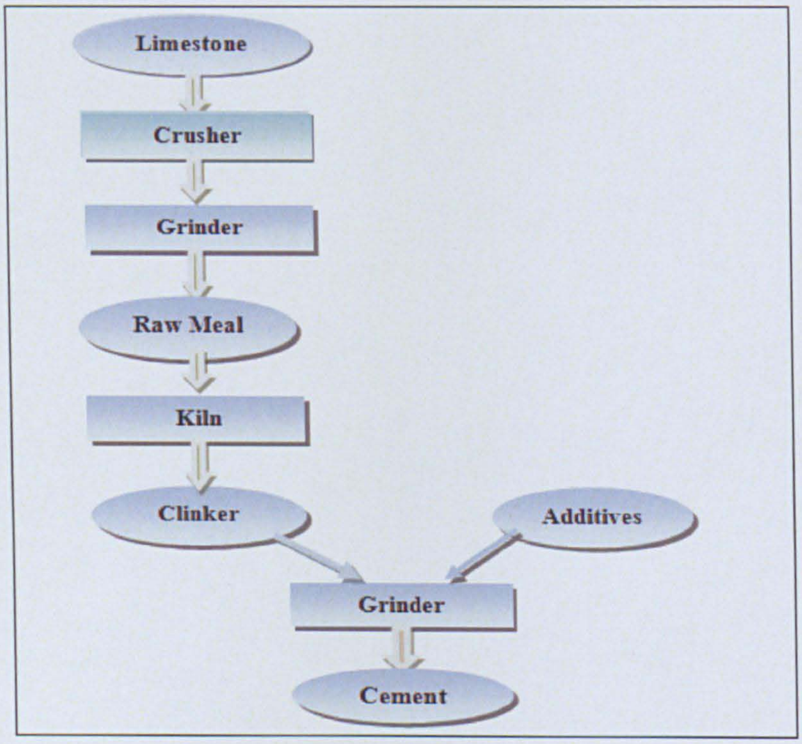


Figure 2.12 Simplified process schematic of cement production (Nathan Martin 1999).

2.5.1 Raw materials preparation

Although more than 30 raw materials are used in cement making, limestone, chalk, and clay are the most widely employed (Greer 1992). A precise raw materials composition is crucial for cement quality and uniformity (Mark Levine 1995). To this end, the raw materials for crushing and grinding should be selected accurately, so that the resulting mixture is of the fineness, quality and chemical composition required for delivery to the Pyro- processing system (G.C.Bye 1983).

The limestone is crushed by a rotating crusher or jawbreaker, together with a hammer mill or roller. The crushed materials are screened by monitors for removal and detachment of stones. After the crushing step, the raw materials are further processed for feeding into the kiln, 1 t of clinker requiring approximately 1.65–1.175 t of raw meal. However, the grinding process varies with the type of Pyro-processing used (G.C.Bye 1999).

2.5.2 Clinker production (burning in kiln)

Clinker is the solid material, produced by the cement kiln stage, which has splintered into lumps or nodules, typically of diameter 3–25 m (Wikipedia 2011). The raw meal is burned at a high temperature (1400°–1450°) for calcining the materials, and then clinkerised to produce clinker. Two main types of kiln have been used worldwide: the vertical shaft kiln, used mostly in developing countries like China, and the rotary kiln, used mainly in developed countries. Vertical shaft kilns, featuring high energy consumption throughout the operation, have been used for cement clinker making ever since Portland cement was invented in 1824 for use as a building material (Ernst Worrell 2001).

The kiln feed for clinker consists of five principal oxides: SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO. These five major oxides are not all present in the raw materials in the form of oxides. Only SiO_2, $A12O_3$, Fe_2O_3 normally exist in the raw materials and combine with CaO in the chemical reactions that form clinker minerals. However, Young and Miller in 2004 demonstrated the chemical reactions occurring in kilns that form CaO from $CaCO_3$ (limestone) and MgO from $MgCO_3$ (dolomite) (PCA 2008), taking into account the national specifications for Portland cement which state that cement must not contain more than 5% MgO (total alkalis limitation) and less than 3% limestone. Therefore, dolomite categorization is essential in assessing the carbonate contents for cement manufacture (BritishGeologicalSurvey 2005).

$$CaCO_3 + heat \text{ -------> } CaO + CO_2$$

800 – 900°C

750 kcal/ Kg CaO

$$MgCO_3 + heat \text{ ------> } MgO + CO_2$$

500 – 700°C

600 kcal/ Kg MgO

Most of the heat is required for limestone and dolomite calcination to release the consequent CO_2 emissions. Since clinker contains 65% CaO and 2% MgO, the calcination heat required is (VDZ Research Institute of the Cement Industry 2008).

For CaO (0.65 Kg CaO/Kg clinker) x (750 kcal/Kg) = 488 kcal/Kg clinker

For MgO (0.02 Kg MgO/Kg clinker) x (600 kcal/Kg) = 12 kcal/Kg clinker

Total = 500 kcal/Kg clinker

However, throughout clinker making the high temperatures involved cause part of the raw mix to change from a solid to a gas. This is called an "ignition loss" and the raw mix is said to have an "LOI" (Loss on Ignition). Because of the LOI, it is necessary to put in about 1.5 Kg of raw mix to make 1 Kg of clinker. Most of the LOI is due to the calcining reaction. It represents a major energy requirement in the cement making process.

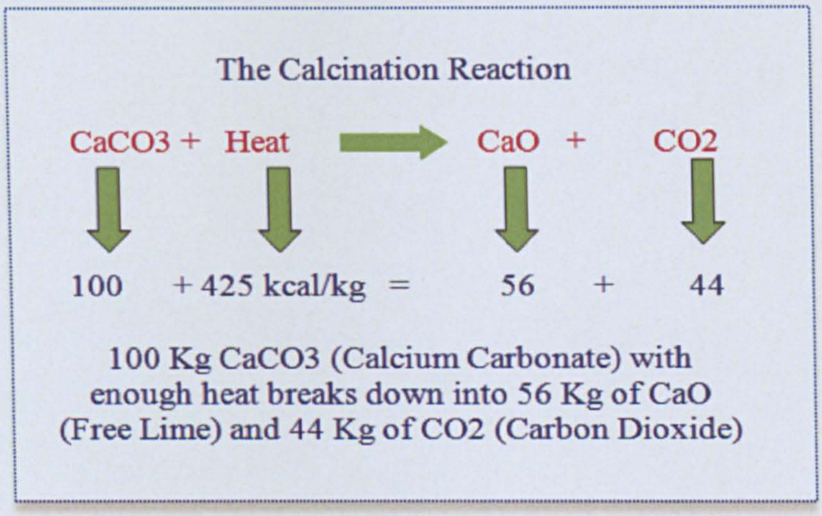


Figure 2.13 Calcining reaction for cement making (Dunbarworks 2007).

The calcining reaction is essential for making cement. In this reaction a compound is divided into 2 other compounds. As seen from the chemical symbols on the two sides of the equation (Figure 2.13), calcium carbonate (the main ingredient in limestone) breaks down into calcium oxide (free lime) and carbon dioxide (CO_2) (David Chrystall Dunbar).

The amount of CO_2 emissions would account for 0.55 ton of CO_2/tonne of clinker. But the amount of CO_2 emitted from the burning of fuel is not included in the previous number as it varies according to the fuel used. However, according to the 2008 PCA report, the amount of CO_2 emissions from fuel burning ranges between 0.25 and 0.5 ton of CO_2/tonne of clinker (VDZ Research Institute of the Cement Industry 2008).

2.5.3 Clinker cooler and finish grinding

Clinker cooler: The clinker is cooled down to 100° by using forced air, then stored in a buffer. Through the addition of 5% gypsum and sometimes different additional materials (e.g. fly ash, blast furnace slag, pozzolana, gypsum, and anhydrite), it becomes what is called cement. To save energy, heat recovered from this cooling process is re-circulated back to the kiln or preheater tower.

Clinker cooling can be performed in a grate cooler, a cylinder (rotary) cooler, or a planetary cooler. In a grate cooler, the clinker is transported on a moving or reciprocating grate, with a flow of air passing by. In a tube or planetary cooler, the clinker is cooled in a counter-current air stream. The cooling air serves as combustion air. The largest part of the energy contained in the clinker is returned to the kiln in this way (Ernst Worrell 2001).

G.C. Bye explained in the first edition of the Portland cement book that the clinker is ground in a ball mill, which is a horizontal steel tube filled with steel balls. As the tube rotates, the steel balls tumble and crush the clinker into a super-fine powder, and the generated coarse material is separated in a classifier, to be returned for additional grinding. But for further usage, another small amount of gypsum is added during a final grinding to control the set, so that it can easily pass through a sieve fine enough to hold water. It can now be considered Portland cement, the properties and setting time of which have been influenced by the fineness of the cement (G.C.Bye 1999), and is finally either stored or dispatched. The finished cement costs $40–$100 per tonne due to the transportation costs. An overview of the production of ordinary Portland cement is given in Figure 2.14.

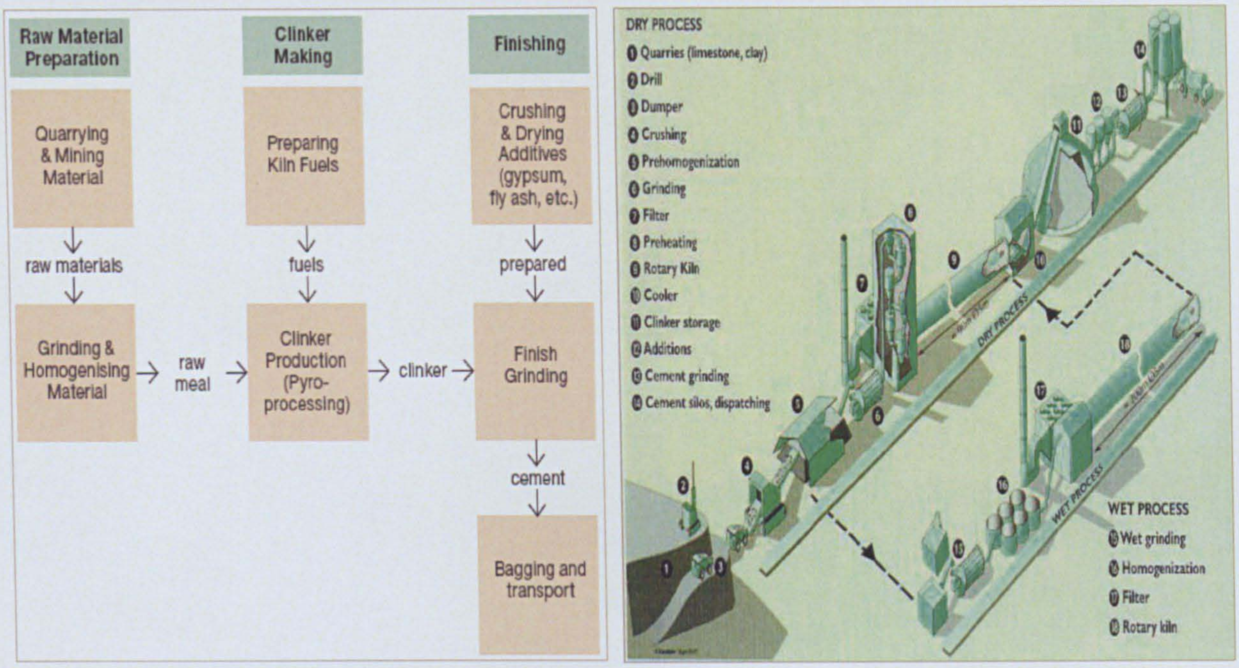


Figure 2.14 Portland cement dry and wet manufacturing processes (Nicolas Müller 2008) (Tania Braga 2009).

The industry currently uses large quantities of blast furnace slag, power station fly ash, silica fume, natural pozzolana, and limestone fines, mainly to substitute for clinker in cement. Some of these are also used as raw materials in the clinker production process (BritishGeologicalSurvey 2005).

2.6 Energy use for cement making

The cement production industry has been recognized as among the principal consumers of carbon-based fuels used to produce heat energy and its technology mainly affects energy saving and emissions released. Furthermore, the limestone decarbonation which is the fundamental step in producing Portland cement plays a key role in releasing additional CO_2 emissions into the surrounding atmosphere, since a composition of main raw materials (raw feed) from limestone and clay is burned at 1450°C to produce clinker. This clinker is cooled and ground later with 5% gypsum rock. 3000 kJ cement is the efficient average fuel energy required for producing 1 Kg of cement, of which 2000 KJ/Kg is needed to produce the chemical reaction of the raw feed in the kiln and 1000 KJ/Kg is consumed by energy loss from radiation, evaporation, and grinding (F. M. Lea 2006).

Frederick M. Lea and C. David Lawrence in1988 and 2006 showed that the theoretical heat energy required to make clinker of Portland cement depends on the quantity of limestone burned in the kiln or the limestone saturation factor, which is calculated from the following equation:

$$\text{Lime saturation factor LSF}= \frac{100\%CaO+75\%MgO}{2.8\%\,SiO_2+1.18\%Al_2O_3+0.65\%Fe_2O}$$

The release of CO_2 emissions into the surrounding atmosphere is the main concern of this research, although CO_2 emission is closely associated with energy consumption throughout the cement manufacturing process and with the decarbonation of limestone, since limestone and chalk are the only natural sources of the calcium required to produce cement. C. David Lawrence, F.Z. Siddiqui and T. Muneer showed that reducing CO_2 emissions is achievable by changing the chemical composition of cement and by reducing the use of carbon-based fuels (Siddiqi 2004).

C. David Lawrence and Frederick M. Lea claimed that the production of the most efficient Portland cement required 2930 kJ per 1 Kg cement. Besides this, each 1 Kg cement requires calcination (decomposition) of 1.209 Kg of carbonate calcium $CaCO_3$, to make 1 Kg of clinker. In addition, decomposition of 1.209 Kg of $CaCO_3$ emits 44/100*1.209= 0.5320 Kg CO_2 into the atmosphere, since:

$$CaCO_3=CaO+CO_2$$

100 56 44 (all Units are Kg)

If the fuel used in firing the kiln contains carbon, then

$$C+O_2=CO_2$$

12 32 44 (all units are Kg)

The release of 94052 cal/ mol or 7837.7 cal/g is equivalent to 32792 J/g. Production of 1 Kg of Portland cement clinker requires the burning of 2930/32792=0.08935 Kg of carbon, consequently releasing 44/12*0.08935=0.3276 Kg of CO_2 into the atmosphere (F. M. Lea 2006). Moreover, cement production requirements for electrical energy can be added to the above calculations. According to Lea and David Lawrence, it has been demonstrated that up to 120 kWh/tonne or 432 KJ/Kg is the electrical energy requirement for cement.

David Lawrence assumed that the achievement of 40% efficiency in electricity generation amounted to 1080 KJ heat energy/Kg clinker. If carbon is again burnt, then 1080/32792.8=0.03293 Kg is required, with the release of a further 44/12*0.03293=0.1208 Kg CO_2 into the atmosphere.

If fuel or natural gas is substituted when burning clinker or generating electrical power, the quantity of CO2 released will diminish. Waste organic solvent is a convenient fuel source, with reduced CO_2 emission for a given heat output, that has recently been developed for clinker burning. More than half the CO_2 released throughout the process of PC production arises from the decarbonation of raw feed, with an additional small fraction resulting from the burning of fuels.

Hendriks and Worrell (C.A. Hendriks 2004) calculated the theoretical heat requirement for clinker, the key ingredient of cement, as 1.75 MJ/Kg. Table 2.8 summarises the amount of energy consumed in different cement production processes (wet, semi-wet, semi-dry and Lepol processes). The rotary kiln is used in industrialized countries, whilst shaft kilns are used in unindustrialized countries like China.

Table 2.8 Worrell and Hendriks summarized energy requirements of different clinker making technologies (C.A. Hendriks 2004).

Energy required	**Rotary Kilns**				**Shaft Kiln**
	Wet	**Semi-wet**	**Dry**	**Semi-dry**	
Fuel Use (MJ/Kg)	5.9	3.6	4.2	2.9-3.4	3.7-6.6
Power Use (kWh/Kg)	0.025	0.030	0.025	0.022	
Primary Energy (MJ/Kg)	6.2	3.9	4.5	3.5-3.7	

However, F. Siddiqui and T. Muneer (2004) showed that the GHG emissions from energy use are affected by the amount of fossil fuel burnt, the type of fossil fuel (i.e., coal generates more GHG emissions per unit of energy than gas, which generates the least), and the emissions associated with extraction and fuel processing (Siddiqi 2004).

Figure 2.15 shows that, from 1990 to 2004, that Japan was the most efficient clinker producer, whilst most countries achieved only modest reductions in the energy required to produce one ton of clinker.

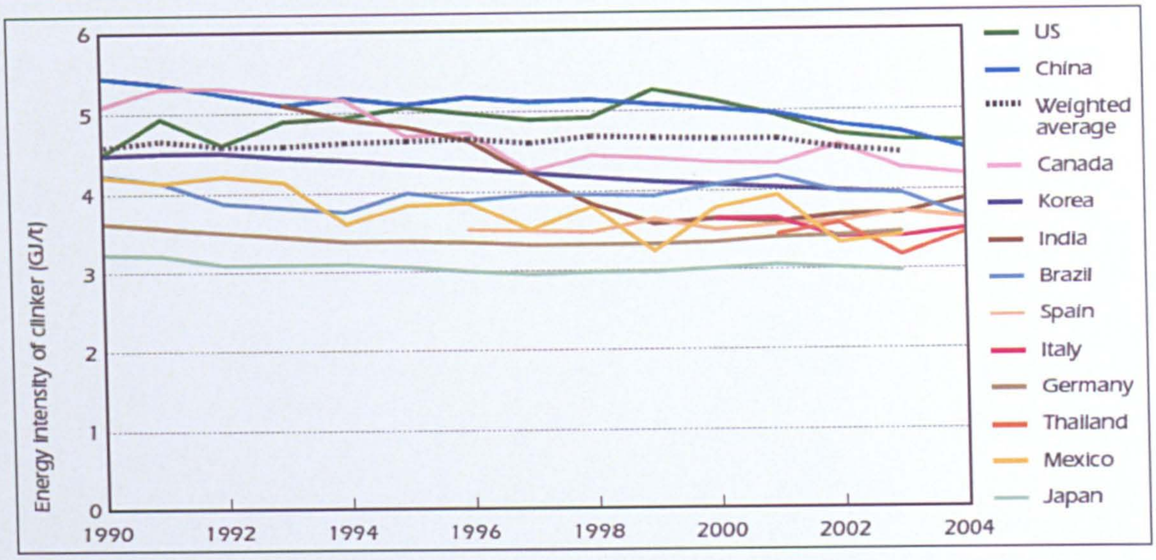


Figure 2.15 Energy requirements per ton of clinker by country including AF (Fred Coito and Frank Powell 2005).

Table 2.9 shows the Key figures for cement production, thermal energy consumption and total CO_2 emitted worldwide. Source: CEMBUREAU: Sustainable Cement Production (2009) and IEA: Energy Efficiency and CO_2 Emissions from the Global Cement Industry (2006).

Table 2.9 Global cement production , thermal energy consumption and amounts of CO_2 emissions

Worldwide cement production, now and in the future	Tonnes per year:
2007	2.77 billion
2020	3.80 billion
2050	5.40 billion
Average thermal energy consumption for 1 tonne of clinker	3500 MJ=120 Kg coal
Electrical energy consumption for 1 tonne of cement	190 MJ
Share of energy costs in the total production cost cement	30-40%
Source of CO_2 emissions in cement production	60% calcination process, 40% fuel
Total CO_2 emitted each year by the cement industry worldwide	1.6 billion tonnes per year or 4% of the total CO_2 emissions

the fuel and Nitrogen oxides (NOx) are generated in two ways: by decomposition of coal or oil in kiln firing, and by the combination of oxygen (fed into the kiln for fuel firing) with nitrogen at a high temperature in the burning zone (Walter L. Greer 2004)As for emissions of CO_2, the total amount released throughout the process of cement production is essentially related to:

- Type of cement production process and the efficacy of process used
- Type of fuel consumed (coal, fuel oil, natural gas, petroleum coke, alternative fuels)
- Ratio of clinker/cement including raw materials calcination and the percentage of additives and clinker substitutes such as fly ash and slag. (C.A. Hendriks 2004)

The CO_2 emissions from cement manufacture released at various locations in the production process fall into two emissions classifications (WBCSD 2011):

1. Direct CO_2 emissions resulting from sources and points owned and controlled by the reporting company, such as:
    - Calcinations of limestone in the raw materials, organic carbon in raw materials, and the chemical process of producing clinker (the main constituent of cement)
    - Conventional fossil fuel burning in kiln
    - Alternative fossil fuels based in kilns (fossil wastes)
    - Biomass kiln fuels (biomass wastes)
    - Non-kiln fuels
2. Indirect CO_2 emissions associated with various sources owned and controlled by another company and related to the process of cement production:
    - Electricity consumed by the cement production process
    - Production and processing of alternative fuels (CO_2 from external power production)
    - Transport of inputs (raw materials, fuels) and outputs (cement, clinker)

Production of 1 tonne of Cement requires 60-130 Kg fuel and 110 KWh of electricity, resulting in the release of 900 Kg CO_2/tonne (Shammakh, Caruso et al. 2008). The intensity of these emissions varies depending on the type of fuel used, from 700 Kg CO_2/1 ton cement in Europe to 900–935 Kg CO_2/tonne in China, India, and the USA, clinker to cement ratio, kiln type, and the carbon intensity of electricity inputs. 40% of these emissions come from direct energy used, 5-10% from indirect energy used (Yeonbae Kim 2002), and 50-55% from the limestone calcination process in the kiln, to turn it into clinker, the main ingredient of cement (Kevin A. Baumert 2005).

However, two methods have been established and published by the cement CO_2 Protocol in June 2005 to calculate the direct process-related emissions (Thompson 2007).

1. Clinker-based methodology:
   This method is based on IPCC Guidelines (2000) as presented in the WBCSD "Cement CO_2 Protocol". This calculation depends on the amount and composition of clinker, as well as on the cement kiln dust amount (CKD), which is removed during the manufacturing process.

CO_2 emissions = [(Cli) (EFcli) + (CKD) (EFCKD)] (1)

Where:

Cli = Quantity of clinker produced

EFcli = Clinker emission factor

CKD = Quantity of cement kiln dust discarded

EFCKD = CKD emission factor

. **Equation 2.1** CO_2 emissions calculation according to the clinker-based methodology (IPCC)

2. Cement-based methodology:
   The calculation of CO_2 emissions depends on the amount of raw materials and their carbonate content, but this methodology accounts for cement production process changes.

The total CO_2 emissions for 1994 were estimated by Ernest Worrell (Ernst Worrell 2001), based on production trends and energy use, but because of the difficulty of data collection regarding clinker production at that time were estimated again in 2000 by 1.588 Mt of CO_2 according to the WRI (WBCSD 2005).

2.7.1 CO_2 emissions from raw materials calcination

Calcination is the release of CO_2 emissions from carbonates during raw meal pre-processing, which is related directly to clinker production. Theoretically, the two earlier methods of CO_2 calculation are equivalent (F. M. Lea 2006). But the CSI Task force decided to focus on the clinker-based method as pointed out earlier. In applying the clinker-based method, plant-specific data will be used by the research as follows:

2.7.1.1 Clinker

Clinker is the key component of cement. Accordingly, calculation of released CO_2 is mainly based on clinker volume produced and an emission factor per tonne of clinker (clinker-based method). The share of CaO in clinker is 64%–67%. The remainder consists of iron oxides and aluminium oxides. CO_2 emissions from clinker production amounts therefore to about 0.5 Kg/Kg clinker. The specific process CO_2 emission for cement production depends on the clinker/cement ratio. This ratio normally varies from 0.5 to 0.95. For the process emissions, there is a calcinations factor of 0.136 Mt of Carbon (Mt/tonne clinker) (0.5 Mt of CO_2/tonne clinker) (1 Mt of CO_2=0.27 Mt) (G.C.Bye 1999).

Equations 2, 3, and 4 show the emission factor calculations for clinker (Siddiqi 2004).

Equation 2.2: $EF_{clinker}$= Fraction CaO8 (44.01 g/mole CO_2 / 56.08 g/mole CaO)

Or

Equation 2.3: $EF_{clinker}$= Fraction CaO* 0.785

The multiplication factor (0.785) is the molecular weight ratio of CO_2 to CaO in the raw material mineral calcite ($CaCO_3$), from which most of the CaO in clinker is derived. CaO content can differ by country of origin and facility.

On the other hand, the IPCC default value for the fraction of lime in clinker is 64.6 percent. This results in an emission factor of 0.507 tons of CO_2/tonne of clinker, as demonstrated below:

Equation 2.4: $EF_{clinker}$= 0.646*0.785= 0.507

2.7.2 Carbon dioxide emissions from conventional kiln fuel

Conventional kiln fuels are fossil fuels including e.g. coal, petcock, fuel oil and natural gas. The preferred approach is to calculate CO_2 from conventional kiln fuels based on fuel consumption, lower heating values, and the matching CO_2 emission factors. Fuel combustion and lower heating values of fuels are measured at the plant site.

2.7.3 Carbon dioxide emissions from AF

Alternative fuels (AF) which are typically derived from wastes, are increasingly used in the cement industry. Therefore without this use, the waste would have been disposed of in another way, usually by land filling or incineration (WBCSD-CSI 2006).

Alternative fuels consist of fossil fuel-based materials in tiny proportions, such as waste tyres, waste oil and plastics, and biomass fractions, including waste wood and sewage sludge. AF act as a substitute for conventional fossil fuels, and the amount of CO_2 emissions differs according to the type of AF consumed.

2.7.3.1 CO_2 from biomass fuels

Biomass is considered climate- and energy-neutral, because emissions can be compensated for by biomass re-growth within a short term, harvested sustainably. However, some forms of biomass fuel such as sawdust may generate CO_2 that might be subtracted from the regular process, where biomass is considered to be CO_2 neutral (WBCSD 2002).Direct CO_2 emission from biomass fuel combustion will be excluded from the total CO_2 emissions, since its emission factor has been defaulted by the IPCC at 110 Kg CO_2/GJ for solid biomass.

2.7.3.2 CO_2 from fossil fuel-derived wastes

Waste fuel, in contrast to biomass fuel, is not climate-neutral. Direct CO_2 from combustion of waste fuel will be calculated and included in the total of direct CO_2 emissions (Gross emissions total). CO_2 emission factors depend on the type of AF used, as specified at the plant area. However, it is preferable at cement plant level to use tyres and impregnated sawdust, which contain both fossil and biomass carbon, taking into account a sufficient waste supply within a reasonable transportation cost distance (WBCSD 2002) .In this regard, the emission factor of waste fuel is based on the share of fossil carbon in the fuel's overall carbon content. But measuring this share is difficult and costly (CEMBUREAU 2007).

2.7.4 CO_2 emissions from electricity

Carbon dioxide emission from electricity consumption represents the final stage in total CO_2 emissions estimation. When the electricity purchase figures are available, approximate overall electricity can be calculated by assuming the emission factor as discussed previously in (G.C.Bye 1999).

2.8 Total CO_2 emissions from cement production

An estimation of total carbon dioxide emissions will be provided in this section for global cement production from 1990 to 2006 (see Table 2.10).

This estimation is based on current available data for the cement sector given by the World Business Council for Sustainable Development (WBCSD-GNR 2008).

Tables 2.11and 2.12 and Figure 2.17 show the carbon dioxide emissions from global cement production in relation to clinker/cement ratio and fuel used. The cement/clinker ratio may vary with the presence of more or fewer additives in the cement (Ernst Worrell 2001). Not accounted for are the carbon dioxide emissions attributable to mobile equipment used for winnowing of raw material, used for transport of raw material and cement, and used on the plant site.The total CO_2 emissions during the cement production process depend mainly on:

- Type of production process (efficiency of the process and sub-processes)
- Fuel used (coal, fuel oil, natural gas, petroleum coke, alternative fuels).
- Clinker/cement ratio (percentage of additives).

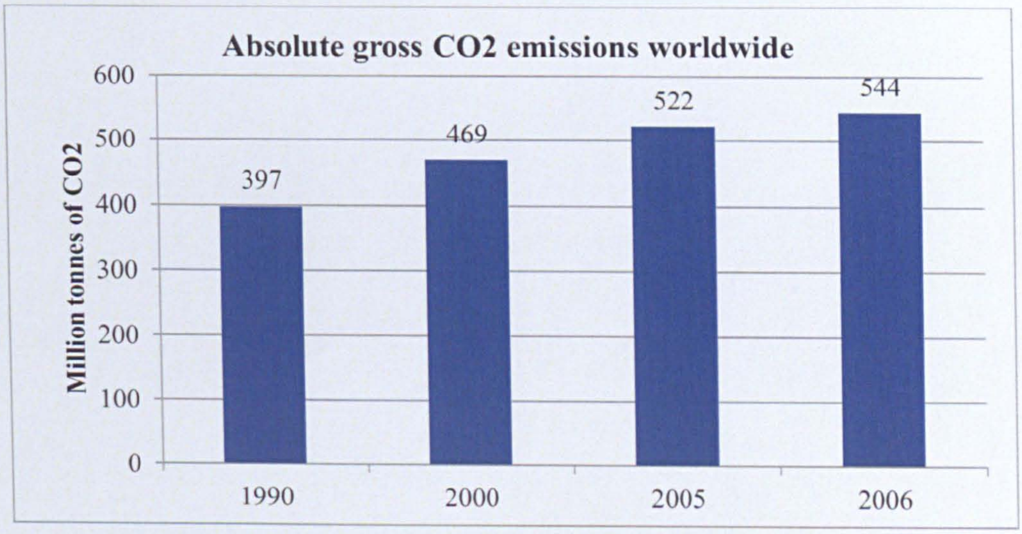


Figure 2.17 Absolute gross CO_2 emissions worldwide (Mt), 1990–2006 (WBCSD-GNR 2008).

Table 2.11 Global carbon emissions from cement production (WBCSD-GNR 2008).

Year	World Cement Production (Mt)	Total clinker Production (Mt)	Total clinker share in cement (%)	Alternative fossil fuel Fossil- waste (t)	Alternative fossil fuel Fossil- waste (%)	Biomass Fuel (t)	Biomass (%)	Fossil Fuel (%)	Absolute Gross CO_2 in World (Mt CO_2)	Net CO_2 in World (Mt CO_2)
1990	512	434	82.9%	2090 000	2.3 %	411 000	0.4%	97.3%	397	394
2000	633	531	82.3 %	5840 000	5.5%	982 000	0.8%	93.7%	469	460
2005	745	599	79.2%	7960 000	7.2%	382 000	2.4%	90.4%	522	509
2006	794	626	78.0%	8760 000	7.5%	422 000	2.5%	90.0%	544	530

Table 2.12 GNR variable in 2006 for the cement industry sector worldwide (WBCSD-GNR 2008).

Variable	Unit	2006	% change since 1990
Number of installation	Number	844	+17%
Clinker Production	M tonne of clinker	626	+44%
Cementitious product production	M tonne cementitious product	801	+53%
Gross CO2	M tonne CO2	544	+37%
Net CO2	M tonne CO2	530	+35%
Gross CO2 per tonne of clinker	Kg CO2/ tonne of clinker	866	_5.3%
Net tonne of CO2 per tonne of clinker	Kg CO2/ tonne of clinker	844	_6.9%
Gross Co2 per tonne of cementitious	Kg CO2/ tonne cementitious product	679	_10.6%
Net Co2 per tonne of cementitious	Kg CO2/ tonne cementitious product	661	_12.1%
Clinker substitution	Clinker to cement ratio	78.0	_5.9%
Thermal energy efficiency	MJ/ tonne clinker	3.690	_14%
Electric energy efficiency	MWh/ tonne cement	111	_3.5%

2.9 Energy efficiency improvement and CO_2 reduction opportunities

Energy savings and GHG emission reductions in the cement industry can be realized through energy-efficiency improvement, increased use of blended cements, replacement of coal with waste fuels, use of waste heat for power generation, and structural shifts, i.e., closing older shaft kilns (most used in developing countries) and building modern rotary kilns. Energy-efficiency improvement reduces carbon dioxide emissions from fuel and electricity use, and reduces the cost of cement production

2.9.1 Replacing high carbon fuel with low carbon fuel (waste used as fuels and ARM)

More than 90% of the energy used in cement production originates in fuels. The remaining (5–10%) primary energy is consumed by electricity. A key option for reducing CO_2 emissions is to lower the carbon content of fuel (by shifting from coal to natural gas). An important opportunity to reduce long-cycle carbon emission is presented by the application of waste-derived alternative fuels.

Waste management and waste disposal options constitute a relatively advanced new services and research sector in industrialized countries, and are regarded as an integrated part of every modern economy. In developing countries, by contrast, there is a lack of such options, so that achieving safe disposal and waste management presents a challenge. Waste is discharged into drains, buried or burned, illegally dumped at unsuitable locations, or taken into landfills that fail to meet the environmental requirements for sound final disposal of waste.

The result is contamination of the soil, water resources and atmosphere, and potential hazards to the health and living conditions of adjacent populations, as poisonous substances and toxic compounds are released into the environment, spread over large areas, enter the food chain, and affect human and animal health.

Accordingly, an environmentally-friendly and economical method of waste management and disposal is a crucial aim in developing improved strategies and technologies. This factor is significantly developed and managed in high-income countries, but is still largely unmanaged in most developing countries (Holcim-GIZ 2006).

Some types of waste management deficiency in developing countries include:

- Lack of appropriate technical infrastructure for controlled disposing of waste.
- Absence of laws, or non-enforcement of existing laws, on the controlled handling of hazardous waste.
- The fact that uncontrolled disposal is the cheapest way to get rid of the waste.
- At the policy level, inadequate attention to the subject of hazardous waste management.
- Little or no knowledge of the damage to human health or the high cost of remediation.

Waste usage in the cement industry reduces both disposal of waste material and consumption of fossil fuels (ECA 2009). Possible disadvantages are adverse effects on cement quality and increased emission of harmful gases. Types of waste used as alternative fuels include:

- Gaseous alternative fuels (coke oven gases, refinery gases, pyrolisis residues, hydraulic oils, insulating oils).
- Solid alternative fuels (waste wood, dried sewage sludge plastic, agricultural residues, used tyres, petroleum coke, and tar).
- Liquid alternative fuels (halogen-free spends solvents, mineral oils, distillation residues, hydraulic oils, insulating oils).
- Biomass waste such as rice husk.

Discarded tyres are the most commonly used AF. It is globally estimated that one billion tyres arrive at the end of their useful life every year. Cement kilns can use either whole or shredded tyre-derived fuel. Japan and the USA are the biggest users of discarded tyres. Tyres have higher energy than coal and, when burned in a controlled environment, produce no more emissions than other fuels. Furthermore, some case studies showed that usage of tyre-derived fuel instead of virgin fossil fuels reduces nitrogen dioxide and carbon dioxide emissions. Heavy residues are captured and locked into clinker (WBCSD&IEA 2009).

In the cement industry waste co-processing is feasible and is current practice. Usage of wastes as alternative fuel is increasingly optimized in cement companies such as Lafarge, Holcim, and Taiheiyo. CO_2 emission has been reduced by 0.1 to 0.5 Kg/Kg cement through waste utilization, as 60% of the waste that can be used for co-processing is biomass, which is CO_2-neutral. At the same time, the results of research carried out by the University of Applied Sciences, North-western Switzerland (Morf 2007)showed that in 2030 in the cement industry of EU nations, 13% of limestone input and 100% of other raw materials input will be replaced by wastes. Table 2.13 summarises the banned materials which are excluded from the co-processing according to its negative impacts on the process of cement manufacturing.

Table 2.13 Non-suitable materials for co-processing and the key reason for exclusion from co-processing.

	Enrichment of pollutants in clinker	Emission values	OH&S	Potential for cycling	Land filling as better option	Negative impact on kiln operation
Electronic waste	x	x		x		
Entire Batteries	x	x		x		x
Infectious & boil active medical waste			x			
Minerals acids & corrosives		x	x			x
Explosives	x		x			x
Asbestos			x		x	
Radioactive waste	x		x			
Unsorted municipal waste	x	x		x		x

2.9.1.1 Recycling and reuse of waste materials to recover energy

Unlike the incineration of wastes, the energy recovery system has as its key objective the recovery of the steam or hot flue gas as a valuable product, since a wide range of organic wastes with specific properties can be burned to obtain energy value either from the steam or from the hot flue gases generated by the combustion process.

The organic component contained in waste materials has the potential to serve as fuel in the combustion device, replacing conventional fossil fuels such as oil or natural gas. Rather than disposing of the inorganic components of waste materials used in the combustion device, such as ash, this ash can be used to replace the conventional raw materials; but further treatment would be required before using it if it contains heavy metals. Energy recovery can be valuable mainly when used in energy-intensive processes such as the process of Portland cement manufacture.

Various types of wastes can be utilized for energy recovery, including (Lawrence Smith 1994):

- Petroleum- or solvent-contaminated soils
- Propellants
- Rubber products
- Solid polymeric materials
- Automobile shredder residue
- Sludges and wood debris.

Any material with a measurable heating value higher than approximately 7.000 kJ/ Kg (3.000 Btu/lb) can be used for energy recovery. But the amount of recovered energy is associated with the moisture content of the waste materials, since materials such as sludges with a high moisture component will yield a reduced amount of energy.

However, substituting waste materials for fuel is an approach frequently applied to the recovery of value from the waste. The ideal energy recovery fuel should be as much like conventional fuels as possible. Cement kilns are fuelled usually with coal, oil, or gas. A high proportion of carbon and hydrogen present as organic compounds, low water content, and low ash content are the perfect conditions for a fuel material, as high ash contents will increase the complexity of dealing with the fly ash and bottom ash.

Physical parameters and desirable properties for feed materials for combustion to recover energy are identified by the EPA (Environmental Protection Agency) to help in choosing suitable waste for use accordingly with advantages and disadvantages of these waste (Table 2.14) (EnvironmentalProtectionAgency. 1994), as follows:

- The high concentration of volatile metals in wastes such as mercury can volatilize and increase the complexity requirements for controlling air pollution.
- The viscosity of liquid fuels is an important physical parameter; liquid waste must be amenable to atomization at acceptable pressures.

- The most desirable waste fuel is relatively low in chlorine (CL) content and liquid, and hot fuel has high Btu content ranging from 25.600 to 41.900 kJ/ kg.

Table 2.14 clarifies the advantage and disadvantage of waste utilization in cement production (G. C. Bye 1999).

Advantages of energy recovery from wastes in cement industry	**Disadvantages of using wastes to recover energy in cement industry**
Hazardous waste fuel usually burns cleaner than coal in cement kiln with lower associated emissions such as (NOx) and (SOx).	Handling difficulties with sludgy waste and solid waste.
There is no need to remove the steel from reinforcing belts in tyres prior to burning process especially since iron is a crucial ingredient in Portland cement. Consequently, burning tyres reduces the need to buy iron ore (EPA 2008).	A consistent waste fuel supply is required by cement plant operators to avoid the need for constant adjustment through the processing parameters [68].
There are financial benefits to both waste generator and cement operators from burning hazardous waste fuels at cement kilns.	Kiln brick loss and bad product can be caused by burning waste fuels with excessive levels of Cl. Consequently, the level of Cl in the total fuels burned should be less than 3%.

2.9.1.1 ARM usage in cement manufacturing process

However, in the process of cement making, the inorganic solid wastes of various types are fed, wet or dry, along with the conventional raw materials (such as limestone, clay, sand, and iron ore) into the higher end of a long rotary kiln and travel down to the lower end. Substitution of raw materials provides fundamentally 95% or more of the main chemical constituents of cement (silica, calcium, aluminium, and iron). Inside the rotary kiln (Figure 2.18), the raw materials substitutes undergo chemical and physical reactions at high temperature, reaching 1450°C, to form clinker, the main component of cement. Both combustion to heat the raw materials and decomposition reactions during formation of cement clinker cause chemical changes such as:

- Partial fusion of the feed materials

- Free water evaporation
- Release of CO_2 from carbonates, as examples of acceptable feed raw materials.

The acceptable waste materials used to replace the conventional raw materials and to recover energy are provided in detail in Appendix 3 (Appendix for Waste Use).

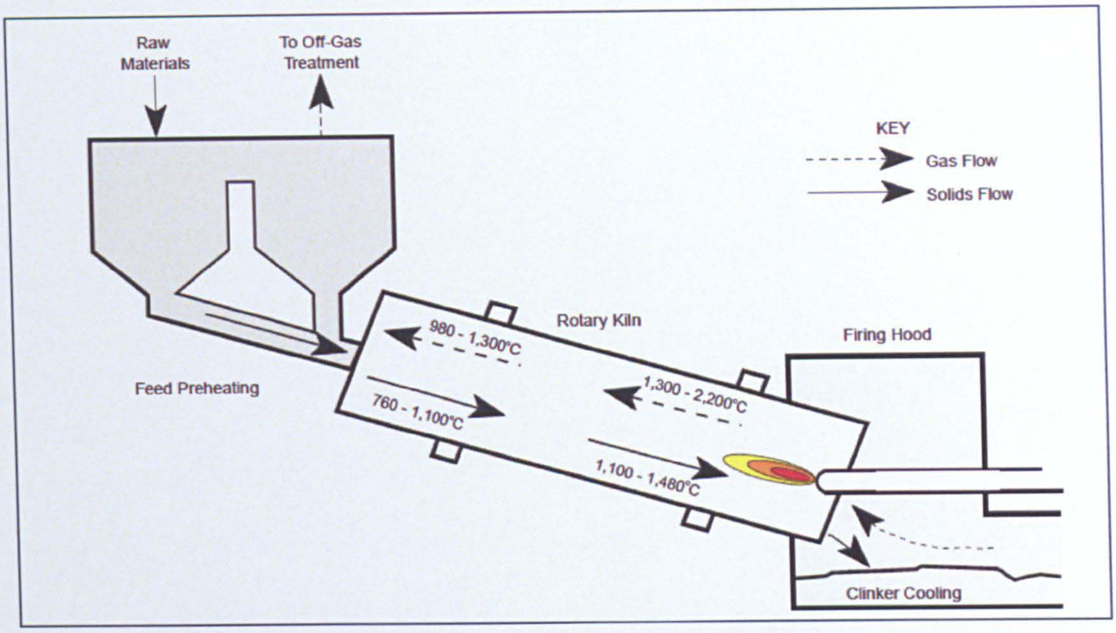


Figure 2.18 Energy recovery from waste burning in cement kiln (Lawrence Smith 1994).

2.9.2 NOVACEM Magnesia Cements (Reactive Magnesia Cements)

There are two practical forms of eco-cement: a type of which the main constituent is reactive magnesium oxide, mixed with industrial by-products such as fly ash or blast furnace slag; and a type in which reactive magnesium oxide is mixed with Portland cement clinker and a pozzolan, to form a type of "composite cement or blended cement". Magnesia cements have recently emerged as a potentially more sustainable and technically superior alternative to Portland cement, since it sets by absorbing CO_2 and as a result gains significant strength. This cement, based on MgO, is an innovative cement and is called Novacem (Chana 2011). Novacem, as a new type of cement, is uniquely positioned to meet the challenge of reducing carbon emissions from the cement industry. Features of this cement are (Antonia V. Herzog 2001), (Al-Tabbaa 2011):

- It is based on magnesium oxide (MgO) and hydrated magnesium carbonates (i.e. hydro-magnesite, 4 $MgCO_3$, Mg $(OH)_2.4H_2O$).
- The performance and cost of Novacem are similar to those of ordinary Portland cement, but with a negative carbon footprint.

- Carbonates produced are heated at low temperature (700°C) to produce MgO, with the CO_2 generated being recycled back in the process.
- The production of 1 tonne of Novacem absorbs up to 100 Kg more CO_2 than it emits, making it on balance a carbon-negative cement product.
- Furthermore, as all the hydration reactions are reversible, Novacem products can be recycled and used to make new products. This makes Novacem cement a much more sustainable alternative to ordinary Portland cement.

2.10 Carbon dioxide removal (cement carbon capture and storage, CCCS)

By applying the carbon dioxide removal technique, a reduction in carbon dioxide emissions will be obtained. In this technique, CO_2 is separated during or after the production process and then stored or disposed of outside the atmosphere. In some cases the recovered CO_2 can be used for other purposes.

In the scope of this technology for low growth CO2 emissions related to cement production, a preliminary calculation of the energy requirement has been applied by (P.S. Bundela and Vivek Chawla in 2010) assuming 90% capture efficiency, dry process (3.35 MJ/Kg clinker), clinker/cement ratio of 0.95, and the fuel oil used, the total required consumption will be about 0.86. The total CO_2 production will then amount to 1.08 Kg/Kg cement, and the overall capture efficiency will amount to 70%. The net CO_2 emissions will be 0.32Kg/Kg cement.

However, this technique needs more research to determine its applicability to cement production facilities and to assess its economic and commercial value.

2.10.1. Definition of CO_2 capture and storage and its contribution to Climate Change mitigation.

According to the Intergovernmental Panel on Climate Change the carbon dioxide capture and storage is defined as: a process consisting of the separation of CO2 from industrial and energy-related sources, transport to a storage location and long term isolation from the atmosphere. Carbon capture and storage is an option of mitigation actions for stabilization of atmospheric greenhouse gas concentrations.

Although a wide range of technologies will be necessary to reduce energy-related CO2 emissions, but the CCS has been considered by the IEA the most important least-cost emissions reduction technology followed by energy efficiency improvement, renewable fuels shifting, and nuclear power usage. According to EIA Blue map scenario, CCS will contribute to 19% emissions reduction by 2050; this contribution will be greater than energy efficiency and renewable energy contributions. Even the nuclear power's contribution will be triple less than the CCS.

2.10.2 Types of CCS technologies

Three types of CO_2 capture systems have been identified by the Intergovernmental Panel on Climate Change (Metz et al 2005): post- combustion, pre-combustion and oxyfuel combustion (Figure 2.19).

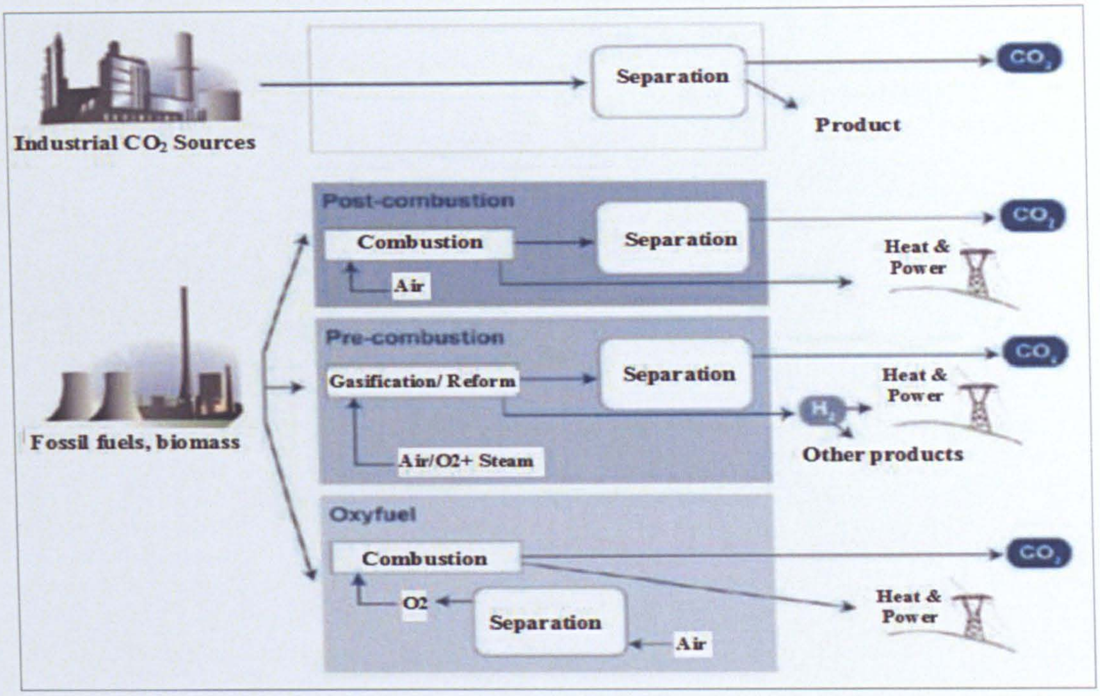


Figure 2.19 Schematic Representation of Capture systems (IPCC 2005)

- **Post- combustion capture of CO_2**

The CO_2 is removed after combustion of the fossil fuel — this is system would be applied to fossil-fuel burning power plants where carbon dioxide is captured from flue gases at power stations or other large point sources. This technology is well understood and economically feasible. It is currently applied in other industrial applications processing at least 0.1 Mt CO_2 yearly, although not at the same scale as might be required in a commercial scale power station. As shown on (Figure 2.21) Pre-combustion process is a technology applied in chemical process for removing Sulphur and CO_2 using chemically active agents to scrub the CO_2 emissions, such as monoethanolamine (MEA) and methyldiethanolamine.

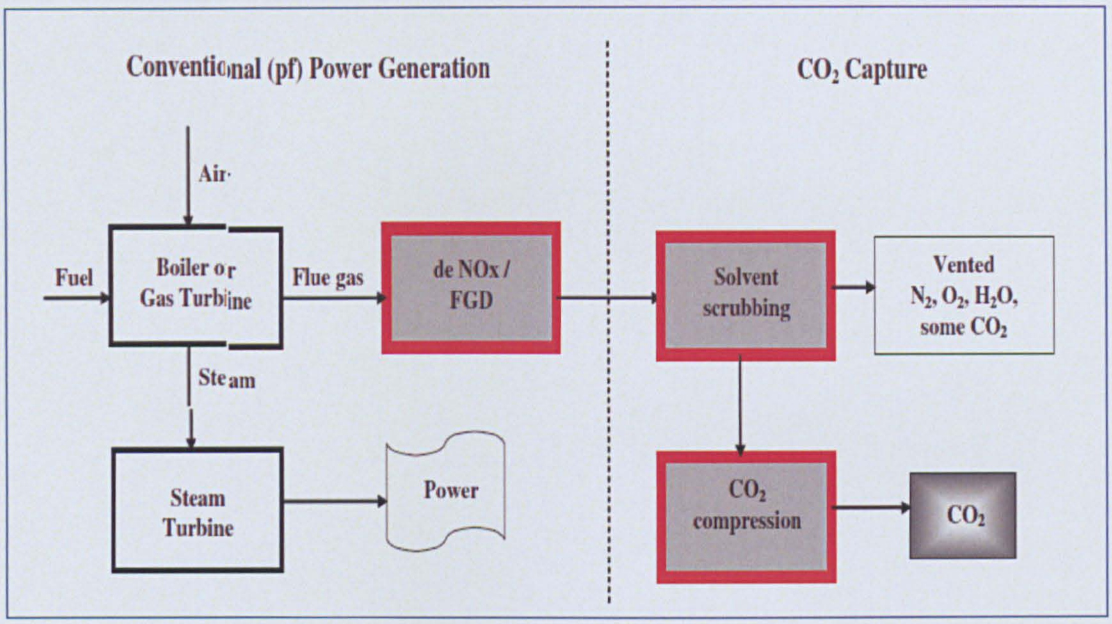


Figure2.20 Illustrative flow sheet for the process of (post-combustion capture), with additional unit operations for carbon capture shown bold (terry F. Wall 2007)

- **Pre-Combustion Capture of CO_2**

Malti Goel explained in his book addressed as Carbon Capture and Storage in 2008 that this system is applied in fertilizer, chemical, and power production. In this technology, the fossil fuel is partially oxidised and the resulting (CO and H_2O) is shifted into CO_2 and more H_2. The resulting CO_2 can be captured from a relatively pure exhaust stream. The H_2 can now be used as fuel; the carbon dioxide is removed before combustion takes place. There are several advantages and disadvantages when compared to conventional post combustion carbon dioxide capture (Malti Goel et al 2008). The CO_2 is removed after combustion of fossil fuels, but before the flue gas is expanded to atmospheric pressure. This system is applied to new fossil fuel burning power plants, or to existing plants where re-powering is an option. The capture before expansion, i.e. from pressurized gas, is standard in almost all industrial CO_2 capture processes, at the same scale as will be required for utility power plants.

The pre-combustion capture is an integrated gasification combined cycle (IGCC) with a shift reactor to convert CO to CO2, followed by CO2 capture, which is called here IGCC-CCS (Terry F. Wall 2007).

As shown on Figure 2.22, in its CCS form the IGCC gasifier product gas is converted to additional H_2 and CO_2 using a shift reaction, with the H_2 burnt in a gas turbine with N_2 as diluents.

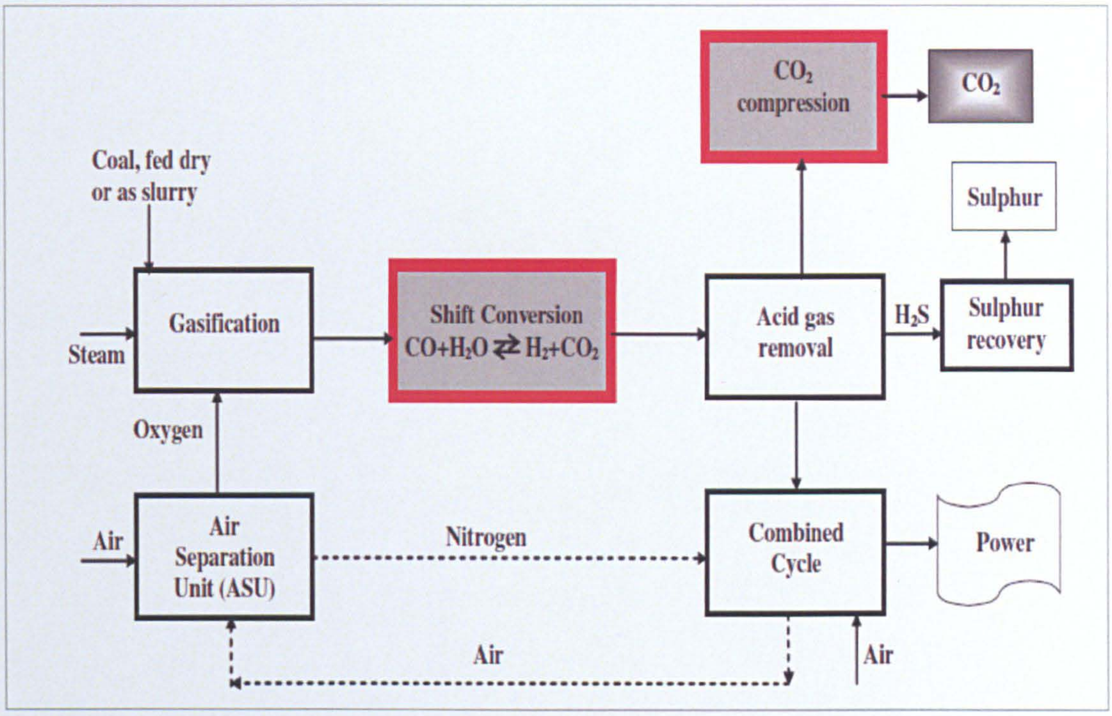


Figure 2.21 Illustrative flow sheet for IGCC (pre-combustion capture) process (terry F. Wall 2007)

- **Oxy-fuel combustion**,

During oxy-fuel combustion the fuel is burned in oxygen instead of air. Cooled flue gas is recirculated and injected into the combustion chamber, to limit the resulting flame temperatures to levels common within conventional combustion. The flue gas is mainly consisted of carbon dioxide and water vapour, the latter is condensed through cooling.

This results in an almost pure stream of CO_2 which is transported to the sequestration site and stored later on. In this regard, the CO_2 is stored as flue gas stream not as a fraction removed from the flue gas such as cases of pre- and post- combustion capture. Therefore the processes of power plant based on oxyfuel combustion are considered as "zero emission cycles" (Jon Gibbins 2008). A certain fraction of the CO_2 produced during combustion will inevitably end up in the condensed water. This water would thus have to be treated or disposed of appropriately to ensure the "zero emission". However, this technique is promising, but a lot of energy is required by the initial air separation step. In Figure 2.22 Oxyf involves combustion in an oxygen/recycled flue gas mixture, containing about 30% O_2 to maintain similar furnace heat transfer, with the CO_2 rich gases being cooled and compressed. Since no CO_2 separation is required.

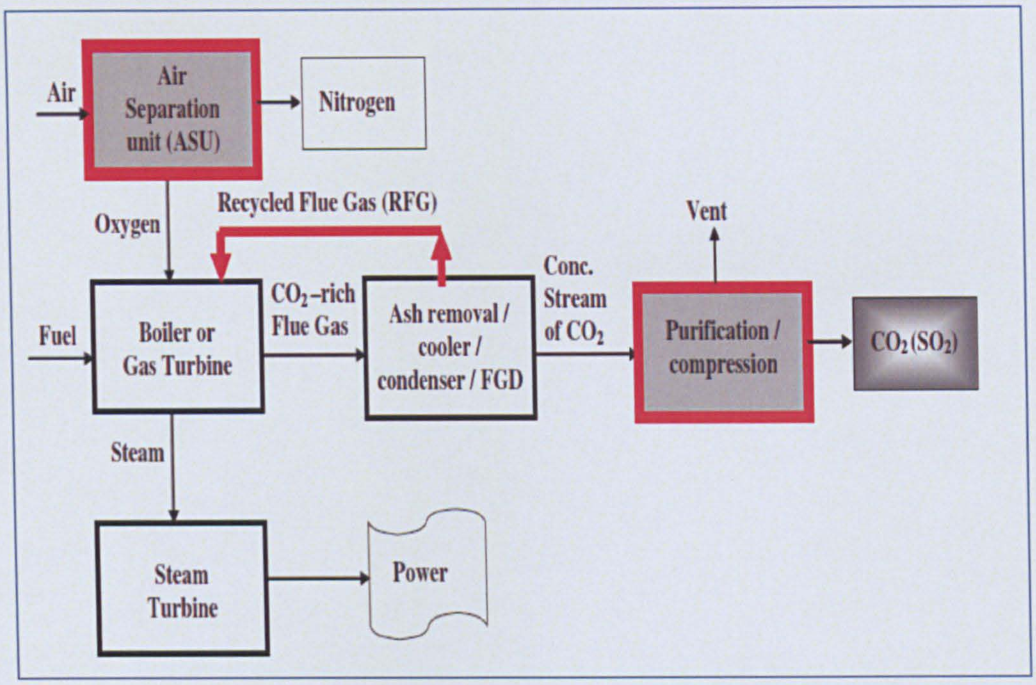


Figure 2.22 Illustrative flow sheet for the process of oxy-fuel (Oxyf), with additional unit operations for carbon capture shown bold (terry F. Wall 2007).

2.10.3 Stages of CCS

- **Carbon Capture**

The first stage captures carbon dioxide from a stationary emission source before it is emitted into the atmosphere. This involves removing the carbon dioxide (CO_2) from the other constituents in the fuel gas stream and conditioning it for transportation, obtaining as pure CO_2 as possible to avoid the storage and handling of other undesirable constituents. The CO_2 capture process constitutes the major cost of CCS (more than 75 %). Several capture technologies: Absorption, adsorption, distillation, membranes.

However, CO_2 management in the cement industry has made good progress in recent decades taking into account various process integrated approaches such as: increase in energy efficiency, use of secondary fuels, use of biomass, and production of blended cements

- **Carbon transportation**

Transportation of the CO_2 to its final storage destination is claimed to be more economical by pipeline, especially if cluster networks are formed for multiple emitters. However, shipping will also play an important role in CCS and could allow CO_2 to be transferred from other countries to the vast stores in deep, onshore or offshore geological formations.

- **Carbon injection and storage potential**

The final stage of CCS involves the storage of CO_2 into secure underground formation, with the favoured choice being depleted oil and gas fields, as well as deep saline aquifers, as it will remain secure in these formations for thousands of years through a number of trapping mechanisms. The storage potential includes:

- Geological storage: likely at least about 2,000 $GtCO_2$ in geological formations "Likely" is a probability between 66 and 90%.
- Ocean storage: on the order of thousands of $GtCO_2$, depending on environmental constraints.
- Mineral carbonation: can currently not be determined.
- Industrial uses: Not much net reduction of CO_2 emissions

Figure 2.23 shows the three stages of CCS including capture process, transportation and various options of storage.

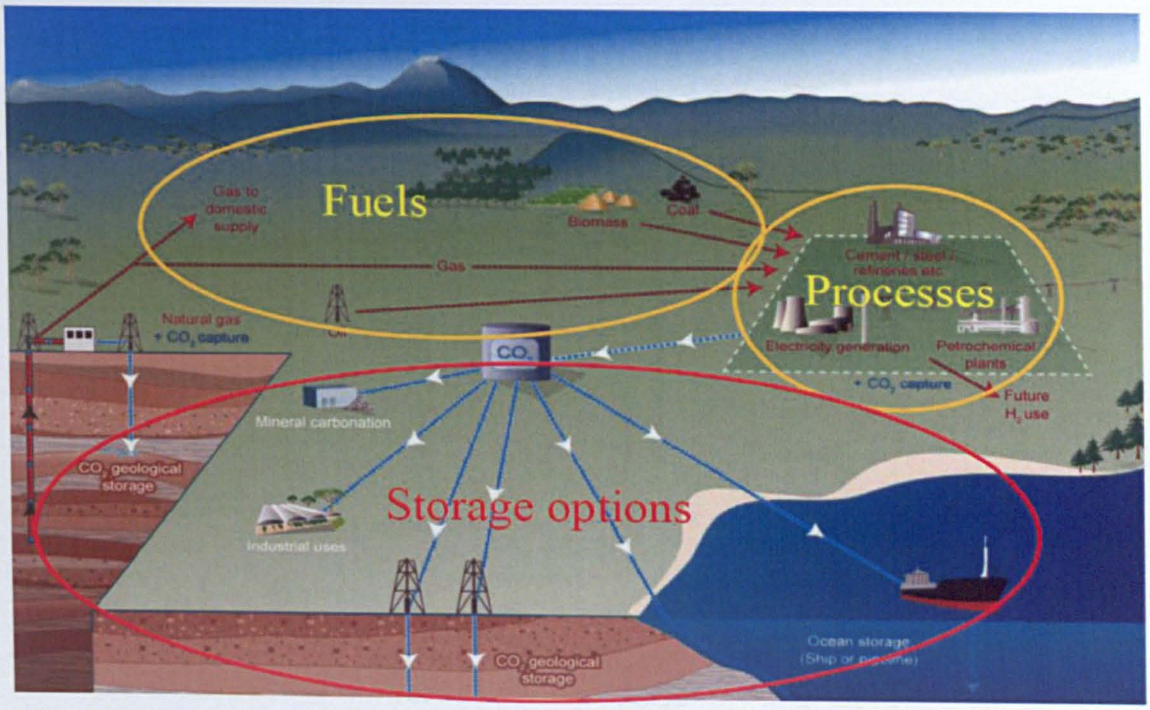


Figure2.23 Schematic diagram of possible CO_2 capture and storage system by Intergovernmental Panel on Climate Change (Bert Metz et al 2005)

2.10.4. Energy requirement for CCS

An additional energy is required for capture, transport, and storage. This results in increasing CO_2 production and overall loss in power plant efficiency. Furthermore, any leakage from transport results in a big amount of CO_2 per unit of product. Figure 2.24 shows the CO_2 comparing emitting per unit of product in plant with capture according to reference plant (IPCC Special Report 2005).

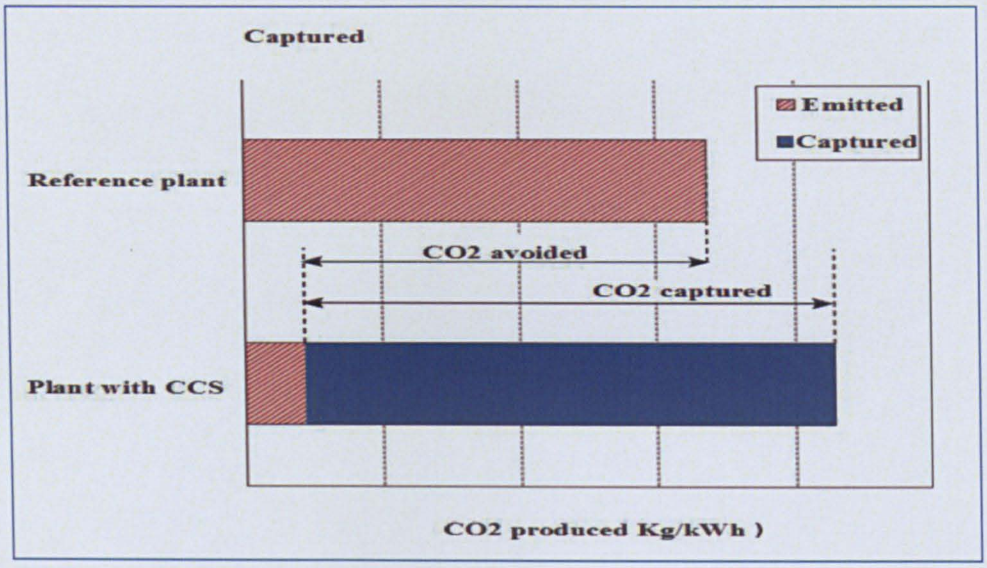


Figure 2.24 Schematic diagram reflects the increasing of CO_2 amount produced in plant with CCS (lower bar) according to plant without CCS (upper bar). (IPCC Special Report (2005)

Today, four power technologies are considered for comparison

- Pulverised coal (PC)
- Natural Gas Combined Cycle (NGCC)
- Integrated Gasification Combined Cycle (IGCC) – Coal
- Oxyfuel Combustion - Coal

Figure 2.25 shows high requirement for fuel to produce a kWh of electricity which is calculated by comparing the same type of plant with and without carbon capture process. Since the increase in energy consumption for an Integrated Gasification Combined Cycle (IGCC) plant with capture in comparison with coal steam baseline plant without capture would be 40% as opposed to the lower value shown in the figure that was calculated relative to the same type of baseline plant without capture.

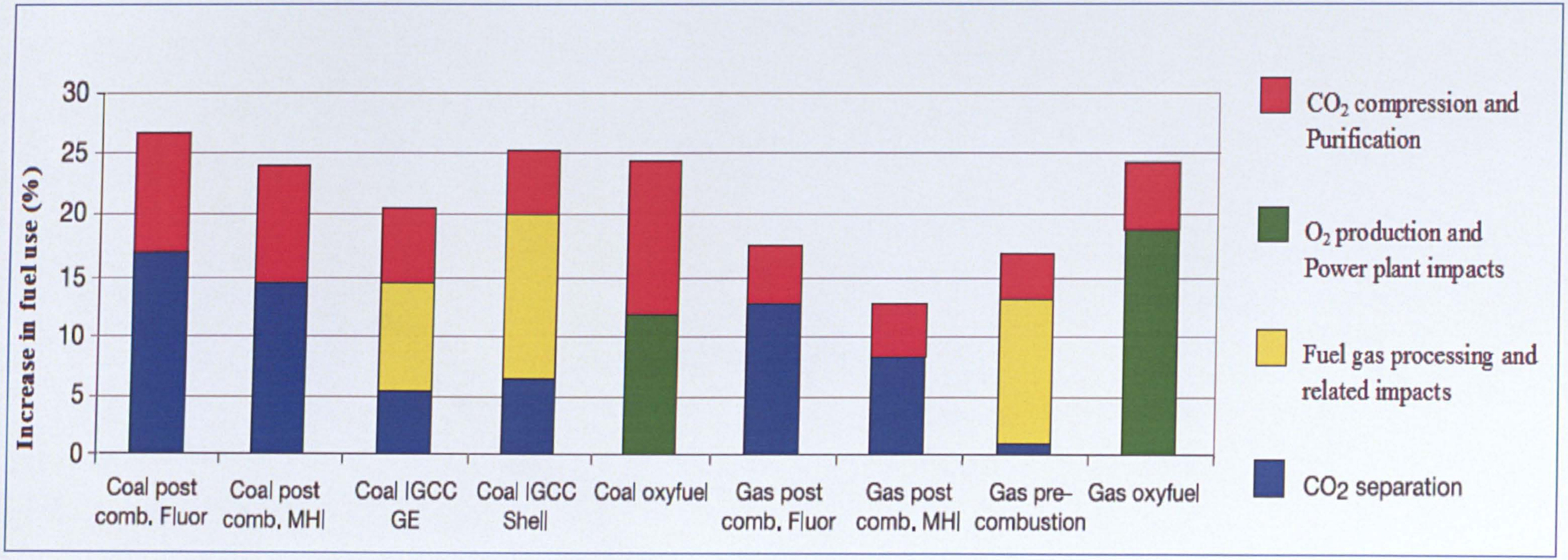


Figure 2.25 Percentage increase in fuel use per kWh of electricity due to CO_2 capture, compared to the same plant without capture (Source data: Davison, 2005; IEA GHG, 2004; IEA GHG, 2003; IEA GHG, 2000b; Dillon et al, 2005).

2.10.5 CCS potential for Cement production

Cement production has been considered as large stationary CO_2 source with emissions of more than 0.1 million tonnes of CO_2 ($MtCO_2$) per year (Table 2.15) (IGPCC 2005). At present, CO_2 is not captured from cement plants, but possibilities do exist. The concentration of CO_2 in the flue gases is between 15-30% by volume, which is higher than in flue gases from power and heat production (3-15% by volume). So, in principle, the post-combustion technologies for CO_2 capture could be applied to cement production plants. Oxy-fuel combustion capture systems may also become a promising technique to recover CO_2 (IEA GHG, 1999).

.**Table2.15** CO_2 released from cement production in 2005(IGPCC in 2005)

Process of	Number of sources	Emissions ($MtCO_2$ year)
Cement production	1.175	932

Another study for Volker Hoenig in 2007 associated with PCA and concern with CCS potential for cement industry showed that all capture technologies are not applicable to cement industry yet. This is due to the high cost of CCS. Although, some capture techniques are more applicable at cement kilns than others, such as pre-combustion technology especially the adaption of the hydrogen combustion could set off a number of research tasks for clinker burning process. Another disadvantage is that process CO_2 from the Calcination of limestone would not be captured. Consequently pre-combustion seems to be the least favourable among the discussed technologies.

Another candidate technology for CO_2 capture at cement kilns is Oxy-fuel technology. Experiences have been obtained from cement kilns in USA which were operated with oxygen. As a result, it has been found that Oxyfuel is applicable at new cement kilns (PCA, Volker Hoenig et al 2007). According to post-combustion capture technology, it has been found by research done by the Portland Cement Association (PCA) in 2007 that it would be applicable either at new cement kilns or at existing cement kilns as this technology is not require fundamental changes in clinker burning process. Post-combustion capture is the most promising carbon capture technology as both types of CO_2 coming from fuel burning or Calcination process is captured in chemical absorption. However, more researches are required to be set before applying this technology at cement kilns.

Chapter 3

Research Methodology

3.1 Sustainable development, WBCSD and the cement industry

Sustainable development involves maintaining the current rate of development whilst leaving suitable resources behind for later generations to continue to develop. Therefore, environmental problems must be tackled by considering their relationship with both the state of the economy and the well-being of society. Taken together, this triple bottom line illustrated in (Figure 3.1) includes everything that we need to consider for a healthy environment, prosperous economy, and stable social life.

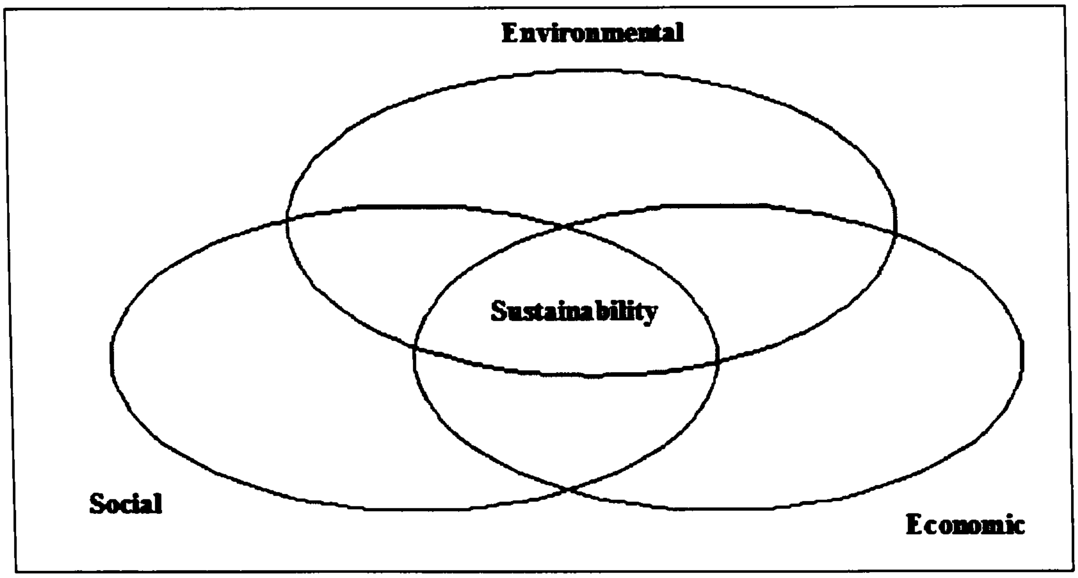


Figure 3.1 The Triple Bottom Line of Sustainability.

Cement production deals daily with a wide range of sustainability issues. 5% of global CO_2 emissions are generated by the cement industry as a result of the limestone calcination process in the kiln, and the requirement that fuels reach the necessary burning temperature of 1450° C. Further impacts are caused by the emitting of dust and the other GHGs such as NOx, SOx, etc; land use for quarries; resource depletion; employees' health and safety; and local biodiversity (WBCSD 2011).

In this respect, The WBCSD provides a comprehensive framework within which to address the key sustainability issues in cement production, identify innovative options for improvement, promote the industry's role in eco-efficiency, and provide recommendations for action and for corporate social responsibility.

However, both renewable and non-renewable natural resources such as air, water, and soil, encompassing mineral as well as biological resources, are used for energy production, and as inputs to resource processing and manufacturing processes. The results of these processes are industry-specific products such as cement, which is eventually transported and used and consumed across all segments of society. The process is an unsustainable linear one because, from an initial extraction of resources, all inputs and outputs move in one direction until disposed of, going through the system only once with no recovery of materials. Aggravating this situation even more is a continuous increase in the demand, and consumption of products and services, which produces pressure for supplementary extraction of natural resources, and for continued expansion of energy production, resource processing, and capabilities of manufacturing. Three critical problems have been created by that unrelenting growth: extreme natural resource consumption, deterioration, and deprivation (of both renewable and non-renewable resources); waste generation and accumulation (including organic and inorganic, hazardous and non-hazardous waste); and environmental impact and deprivation of air, water, and land. These serious challenges must be tackled for achieving sustainability (Abdel-Mohsen Onsy Mohamed 2010).

On the other hand, a new diagram for the SD approach was identified by Jorge A. Vanegas and Annie R. Pearce in research conducted at the Georgia Institute of Technology, showing that the process of SD is a closed cyclical system not a linear one (Pearce 1996), an example being the cement manufacturing process illustrated in (Figure 3.2). Their research confirmed the potential of recovery from waste, including direct reuse, remanufacture of reusable components, reprocessing of recycled material, and raw material generation.

In waste disposal policy it is recognized that a certain amount of waste is inevitable and will require disposal in ways that are not detrimental to the environment. However, environmental technologies address the need to incorporate proactively, within every element of the system, strategies and mechanisms that mitigate environmental impacts at the root (that is, before the impact occurs, through preservation application, pollution prevention, avoidance, monitoring, assessment and control systems), and also to implement corrective actions such as remediation or restoration when some damage to the environment has already taken place.

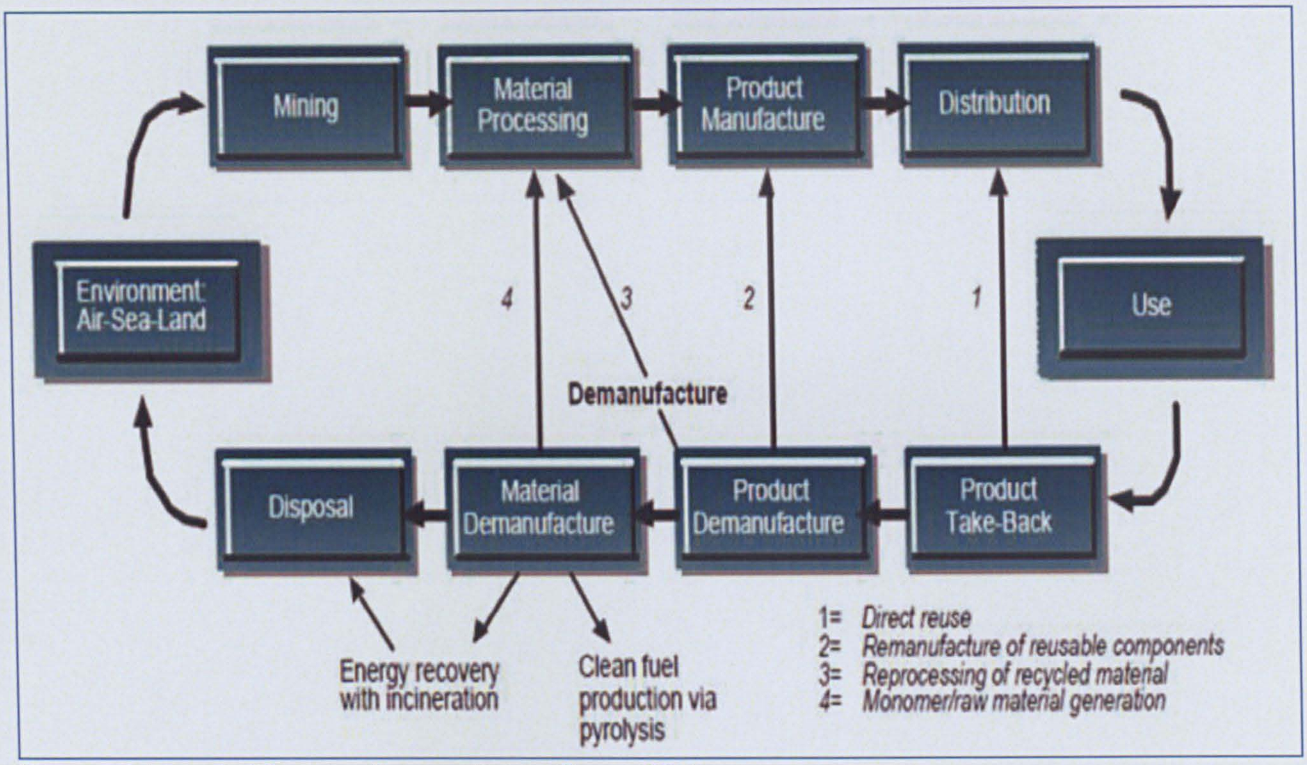


Figure 3.2 A sustainable system for manufacture (Pearce 1996)

3.2 WBCSD sustainability initiative and the cement industry

The World Business Council for Sustainable Development (WBCSD) is a group of 200 international companies united by a joint commitment to sustainable development via economic growth, ecological balance and social progress.

WBCSD members are drawn from 30 countries and 20 main industrial sectors. The Council also has a global network of 35 national and regional business councils and partner organizations, involving more than 1000 business leaders globally. In 2002, cement manufacturers and other leading global cement companies came together under the auspices of the WBSCD to create the Cement Sustainability Initiative (CSI). The CSI has been created to help the cement industry address the challenges of sustainable development. In creating its “Agenda for Action” (WBCSD 2002), the CSI identified and is addressing the major sustainability issues of the cement industry. These are:

- CO_2 and Climate Protection
- Responsible use of Fuels and Raw Materials
- Employee Health and Safety
- Emissions Monitoring and Reduction
- Local Impacts on Land and Communities

In 2006, the cement industry reported publicly on its implementation of the CSI. In 2008 the Cement Industry Sustainability Report gave an update on progress in implementing the CSI.

In June 2008, the CSI released its 5-year update reporting progress in all areas of the Agenda for Action. Significant accomplishments include the development and release of:

- CO_2 Accounting and Reporting Standard for the Cement Industry
- Guidelines for the Selection and Use of Fuels/Raw Materials in the Cement Manufacturing Process
- Communication and Stakeholder Involvement: Guidebook for Cement Facilities

In December 2008, the Cement Sustainability Initiative's "Climate Actions" report was released, detailing the results of industry efforts to address major sustainability challenges. These include:

- A sector-specific CO_2 Accounting and Reporting Protocol,
- A global database of cement plant energy and emissions performance,
- A new approach to the Clean Development Mechanism, and
- Ways in which the cement industry could be a specific sector in the new global, post-2012 international climate framework.

3.3 The research program (Toward a Sustainable Cement Industry)

The report made ten key recommendations regarding means by which the cement industry could progress on the path to sustainable development, in areas of: climate protection, resource productivity, emissions reduction, employee well-being, community well-being, ecological stewardship, regional development, business integration, innovation and industry cooperation. Therefore, the ten major companies involved in the Cement Sustainability Initiative (CSI) have chosen to develop an agenda for action for these reasons (WBCSD 2002):

- To prepare for a more sustainable future by efficient use of natural resources and energy.

- To individually understand and build new market opportunities through process innovations which achieve greater energy efficiency and cost savings in the long run, with a reduction in environmental impacts.
- To provide a framework for engaging external stakeholders.
- To provide a framework through which other cement companies can become involved.

In 2002, the committed cement companies (WBCSD) identified six key areas in which the Cement Sustainability Initiative can make a significant contribution to the achievement of a more sustainable society:

- Climate protection
- Fuels and raw materials
- Employee health and safety
- Emissions reduction
- Local impacts
- Internal business processes that run through the other five areas, effective management systems, stakeholder engagement and reporting.

These areas determine the work program for the Cement Sustainability Initiative over the next five years. For each of these six areas, both joint projects and individual actions are to be undertaken:

- Joint projects will involve a number of companies working together to deal with a specific project, often in conjunction with stakeholders, for example to produce guidelines, and participation in them will be voluntary.
- The individual actions will be taken by companies separately in their operations. These would include, for instance, using the guidelines developed as part of the joint projects to help set and report individual company targets.

However, joint action is at the heart of the work program, and individual companies take responsibility for carrying out their commitments in compliance with local regulations.

In this respect, and in keeping with the WBCSD initiatives, an environmental evaluation and investigation was conducted among the best performance cement companies in the world regarding the environmental issues related to their cement manufacturing process, viability of potential alternative fuels, and emissions reduction opportunities. Additional aims were: to benchmark the current status of the identified cement company; to examine qualitatively more sustainable materials and alternative methods and production technologies; and to make comparisons.

3.4 Response of the cement industry to the WBCSD

The World Business Council for Sustainable Development (WBCSD) was set up in 1992. Its members come from 20 different industrial sectors and 30 countries. In 1999 Dr. Mostafa Tolba chaired the CSI group, which was a union of ten major cement companies sharing joint and individual commitments to the three pillars of SD: social progress, environmental balance and financial growth (Agenda for Actions WBCSD 2002).The main goals of the WBCSD-CSI are to:

- Identify key issues for the industry
- Assess the industry's performance against key sustainability measures
- Provide vision and recommendations for action
- Prompt an actionable agenda for industry leaders to follow; these actions were signed up to by CSI members in 2002.

As earlier mentioned, both joint and individual projects were set by the Agenda for Action. Six Task Forces were established for dealing with critical issues identified in five of the six key areas (the sixth being internal business processes affecting the first five):

- Climate protection
- Use of fuels and raw materials
- Employee health and safety
- Emissions reduction
- Local impacts on land and communities

The following table summarizes the joint and individual commitments of the participating cement companies including Lafarge, Holcim, and Taiheiyo, in addition to the key performance indicators chosen by WBCSD and indicators related to assessment of the environmental impact of the cement manufacturing process. These indicators are employed by research in response to the WBCSD initiatives.

Table 3.1.a Achievements of CSI members (WBCSD-CSI 2010).

Joint actions	Agenda for Action Commitments		Accomplishments of CSI companies
	Joint Commitments	Individual Commitments	
1.CO_2 and Climate Protection			
In 2003, CO_2 Accounting and Reporting Standard for Cement Industry was created in relation to the GHG Protocol established by WRI-WBCSD in 2001 and updated in 2005.	Develop CO_2 Protocol for cement industry in collaboration with WRI-WBCSD and create tools to assess cement companies' mechanisms for reducing CO_2 emissions.	Apply the tools set by CO_2 Protocol to report annual CO_2 emissions, set up policy for climate change mitigation, and publicize the progress made and targets by 2006.	80% of CSI members had employed the tools of the CO_2 Protocol. Up to 2011, all 10 main companies set and published their CO_2 emissions targets according to the protocol tools.

Table 3.1.b Achievements of CSI members.

Joint actions	Agenda for Action Commitments		Accomplishments of CSI companies
	Joint Commitments	Individual Commitments	
2.Responsible Use of Fuels and Raw Materials			
In 2005, CSI members created a set of Guidelines for the Selection and Use of Fuels and Raw materials in the Cement Manufacturing Process. These guidelines were built upon principles of SD, eco-efficiency and industrial ecology, and showed the potential of waste recovery as a source of energy. This document covered two main sections: Principles for selection of fuels and raw materials such as by-products from domestic, industrial, or agricultural sources; and KPIs, including Specific heat consumption of clinker production (MJ/tonne clinker), Rate of AF, Biomass fuel, ARM, and Clinker to cement ratio.	Develop a set of guidelines for the responsible use of conventional and alternative fuels and raw materials in cement kilns. 17 cement companies reported and published their performance in GNR initiatives.	Employ these guidelines and indicators to improve use of fuels and raw materials.	These guidelines had been employed in the cement operation of each company by 2006. Using by-products as fuel reduces the amount of virgin fossil fuels needed, and thus reduces the associated environmental impact. Cement kilns can be used to recover energy from many non-hazardous wastes such as tyres and biomass, as well as from some hazardous wastes.

Table 3.1.c Achievements of CSI members.

Joint actions	Agenda for Action Commitments		Accomplishments of CSI companies
	Joint Commitments	Individual Commitments	
3.Employee Health and Safety			
In 2004, all members of CSI made a commitment to report data for health and safety of their employees as indicated in "<u>Health and Safety in the Cement Industry: Examples of Good Practice</u>" (2004).This document prompts companies to establish KPIs, covering number of fatalities and number of lost time injuries.	Monitor health and safety performance of CSI members' employees, and set up system for sharing information and making recommendations, based on the best performance companies.	Respond to the recommendations of the Health and Safety Task Force on systems, measurement and public reporting.	12 out of 18 companies reporting in 2006 had no fatalities. Since 2003, the fatality rate (per 10,000 employed) has declined by 33%, whilst the lost time injury rate (per million man hours worked) has declined some 44%.

Table 3.1.d Achievements of CSI members.

Joint actions	Agenda for Action Commitments		Accomplishments of CSI companies
	Joint Commitments	Individual Commitments	
4. Emissions Monitoring and Reduction			
In 2005 the Guidelines for Emissions Monitoring and Reporting were developed by CSI members to meet the main objectives related to emissions monitoring during the cement making process and to provide accessible information on these emissions, in order to supply the cement industry with a tool for gathering relevant information with which to set targets for emissions reporting on an industry-wide scale.	Find means of more readily obtaining data on emissions such as GHGs. and provide a common framework for all members of CSI. Identify the sources of emission. and move from reducing emission intensity to reducing absolute emissions by 2008.	Set individual emissions targets and report on progress toward these targets. Make these data easily accessible in companies' annual reports.	

Table 3.1.e Achievements of CSI members.

Joint actions	Agenda for Action Commitments		Accomplishments of CSI companies
	Joint Commitments	Individual Commitments	
5. Local Impacts on Land and Communities			
In 2005 the Guidelines for an Environmental and Social Impacts Assessment (ESIA) were accessible by the public, addressing the environmental and social issues related to the impact of quarry work and cement plant. This document identifies KPIs related to rate of rehabilitated quarry, land use, biodiversity and ecosystem, and health and safety of the local community.	Develop specific policy for all cement plants and quarries to assess the environmental and social impacts associated with cement operations.	Use the ESIA guidelines and improve specific tools for quarries rehabilitation and community engagement.	The ESIA guidelines had been employed by all members. Reports from 9 out of 11 companies showed quarry rehabilitation plans in place for 70% of sites. Developed means of addressing community engagement and biodiversity issues at members' quarry and plant sites.

These actions have been continuously and transparently taken by the WBCSD who keep reporting on progress to support other cement companies' engagements. Table 3.1 reviews the achievements of CSI members, including companies' individual operations.

The research performance indicators of the present study were fundamentally based on the WBCSD initiatives, taking into account the above actions to evaluate the sustainability performance of selected case studies, with particular reference to cement production, and benchmarking their performance against the comparators of WBCSD initiatives and against each other, so that these case studies are considered by WBCSD to represent best cement performance worldwide.

Chapter 4

Case Study for Lafarge Cement Company

4.1 Lafarge commitment to the WBCSD

Lafarge has been committed to the WBCSD since its creation in 1998 for the purpose of achieving SD in three aspects (environmental protection, economic growth, and social progress). The WBCSD is a collaboration of 180 international companies who share the commitment to these three aspects. In 2000, Lafarge enrolled in the Cement Sustainability Initiative (WBCSD-CSI 2006) along with 10 other members for an initial period of 5 years to develop a sectorial approach to sustainable development, with an emphasis on: climate protection, consumption of fuels and raw materials, health and safety of workplace and employees, emissions reduction, local impact, community engagement, and internal processes of company business. According to the WBCSD, Lafarge is world leader in building materials, with top-ranking positions in all of its businesses and distributed widely worldwide over 70 countries (Figure 4.1).

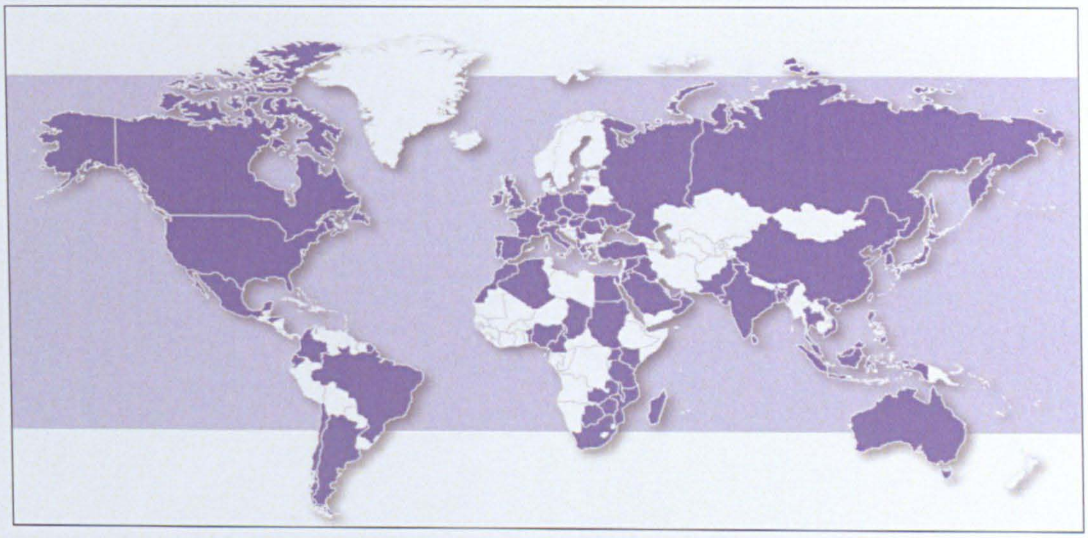


Figure 4.1 World map of Lafarge's presence as at December 31, 2010 (Lafarge 2011)

Lafarge participated in key WBCSD projects, as follows:

- In 2006, publication by all ten companies of their individual performance data and targets for CO_2 emissions, applying the GHG Protocol initiative of the WBCSD-WRI to measure, monitor, and report the companies' emissions.
- A measurement and monitoring standard for reporting and accounting CO_2 emissions (GHG Protocol), the first edition being published in 2001. This protocol has developed a suitable calculation tool based on the standard of each sector and corporation to assist them in calculating their GHG emissions (GHG Protocol website (EuronextParis 2006).

4.2 Environmental Commitments

Three environmental commitments have been set by Lafarge: preserving resources, managing quarries, and limiting resources.

4.2.1 Limiting and recycling wastes

Producing 1 ton of cement requires 1.6 tons of raw materials and 100 Kg of oil equivalent as fuel, which are non-renewable resources (Lafarge 2002).

Therefore, technologies for reducing consumption of natural and non-renewable resources, reusing and recycling waste, and reducing CO_2 emissions, have led to the creation of the industrial ecology concept aimed at achieving sustainable development for waste recovery at cement production (Figure 4.2). The concept was defined by Robert Frosch and Nicolas Gallopoulos, research managers at Lafarge (Lafarge 2008), as follows: “Each transformation operation, independently of another, consumes raw materials, provides the products that we sell and the waste that we stock. We must replace this simplistic method with a more integrated model”.

However, the impact of collecting and treating waste on the environment has been recognized by Lafarge by applying industrial ecology, as divided into two main categories (LafargePublications 2007):

- Resource recovery and waste utilization through replacing either raw materials or fossil fuels with this waste, and using these wastes as mineral components.
- Reducing the amount of wastes from construction.

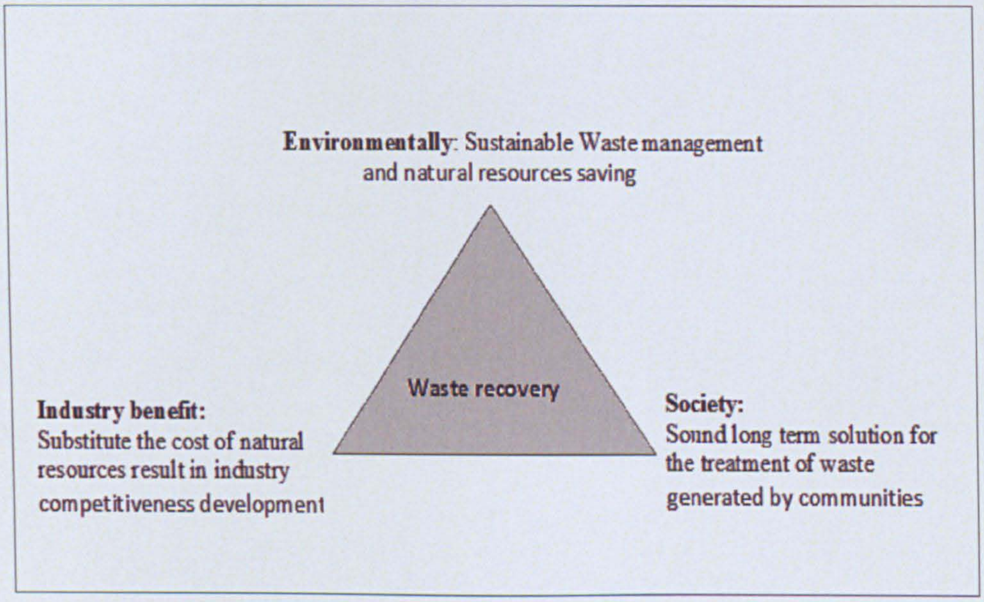


Figure 4.2 waste recovery systems.

The AF usage at Lafarge could be liquid or solid (Table4.1) viscous liquids or sludge, which have been successfully used. The most important factors to evaluate in these AF are related to the heating value of the fuel substituted and the content of ash, moisture, and halogen in this fuel. Usually, the fuels are burned at different points in the kiln in cement manufacturing (EuronextParis 2005). Although it is normal to burn large quantities of fuel with various low heat values in some locations, especially in the secondary furnace and in the middle of the kiln when it is a long one, it is important to burn fuel with a high heat value in the cement kiln, to maintain the high temperature of the flame continuously to enhance the speed of combustion and to produce a high quality clinker using the maximum production capacity of the kiln.

Table 4.1 Types of AF used in cement manufacture at Lafarge worldwide.

Various types of AF used in cement manufacturing with the same heat values approximately	
Scrap tyres (13000–15000 Btu/1b)	Oils (including used and waste) or solvents (Btu/1b varies)
Plastics (10000–16000 Btu/1b)	Wood products (5000–8000 Btu/1b)
Municipal refuse (4000–8000 Btu/1b)	Rice hulls (6000–8000 Btu/1b)
Coal tar sludge (7000–10000 Btu/1b)	Carbon fly ash(900–1500 Btu/1b)
Meat & bone meal (4000–8000 Btu/1b)	Spent activated carbon (10000–12000 Btu/1b)
Carbon black residue (12000–14000 Btu/1b)	Spent toner (12000–15000 Btu/1b)
Off-spec consumer products (Btu/1b varies)	Spent aluminium potliner (4000–8000 Btu/1b)
Spent water treatment resins (6000–12000 Btu/1b)	Hazardous waste (8000–13000 Btu/1b)

4.3. The economic downturn and alternative fuels

Unique opportunities have arisen during the economic downturn for improving innovative fuels programs, as it is the right time to operate beneficial projects of alternative fuel use with minimum risk (Gossman 2009). For Lafarge, the recent economic downturn has offered cement plants a proven means of improving their economic prospects through the use of alternative fuels as shown in (Table 4.2), for the following reasons:

- The economic recession has placed cement plants under great pressure to reduce their operating costs through using AF, as the cost of fuel consumption accounts for the major portion of the total cost.
- The demand for clinker consumption, and consequently the production of cement, decreased during the economic recession.
- The economic downturn in goods prices turned waste material into valuable material, increasing the revenue from its disposal.
- More attention will be paid to small capital projects such as AF projects.
- The economic downturn creates better conditions for obtaining the required authorizations for alternative fuels projects.

Table 4.2 Environmental expense savings according to 1990 levels (LafargeAggregates&ConcreteUK 2010).

Reduction in environmental expense	2010	2009	2008
Reduction of CO_2	22%	16%	18%
Energy efficiency	17%	15%	13%
Natural resources	8%	8%	10%
Comfort and quality of life	7%	5%	6%
Others	42%	51%	47%
Spend in million Euros	153	152	160

4.4 Alternative fuels and raw materials (AFR) usage in the cement manufacturing process at Lafarge

The valuable utilization of waste results in decreased reliance on naturally occurring raw material and fuels required in the process, and provides a safe and effective purpose for materials that otherwise would be considered useless. The future goal of Lafarge Cement is to highlight the beneficial reuse of materials, meeting WBCSD objectives for resource recovery and contributing to the reduction of energy consumption, greenhouse gases and other criteria pollutants. The factors determining the alternative materials and the various types of fuels that can be used beneficially in the cement manufacturing process at Lafarge will be evaluated in this section. In terms of alternative fuel impact, biodiesel is considered one of the most non-toxic and eco-friendly alternative fuels, offering reduced carbon monoxide emission and cleaner burn compared to petroleum-based diesel fuel (Ernst Worrell 2008).

On the other hand, some alternative fuels have negative economic impact, an example being grain. The usage of grains as AF at Lafarge has increased the demand for grain to 81 million tonne worldwide, which was not met because of unsuccessful grain production, resulting in a shortage of the world's grains (Lafarge-SR 2008).

In terms of raw materials, there are some materials the constituents of which may not substantially match the chemical requirements, thus having operational effects on the process (Schreiber 2007). These elements include sulfur content, alkali content, chlorine content, and other minor constituents. Any changes in sulfur quantity, either increasing or decreasing the amount entering the kiln process through raw materials or fuels, can confuse the sulfur balance in that process.

In addition, the amount of chlorine added to the kiln system must be within limits, otherwise the kiln process may be affected negatively, as any further addition of chlorine may change the CKD compound, resulting in difficulties with cement kiln dust (CKD) collection in the associated pollution control device. Certain minor constituents may have this adverse effect (Schreiber 2007).

Although ARM usage faces these potential obstacles, it also offers to various materials which would otherwise be discarded the potential for recovery as valuable resources in the cement manufacturing process. These materials have been utilized for cement making at Lafarge. Table 4.3 shows that the substitution percentage of ARM has been increased from 8.2% in 2000 to 10.56% in 2010, decreasing in return the natural raw materials consumed in same years.

Table4.3 Rate of raw materials consumed at Lafarge including the alternative raw materials

Improvement of RM consumption at Lafarge	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Natural raw materials consumption %	91.8	90.3	89. 5	89.47	90.20	89. 5	89.70	88.60	90.34	89.85	89.44
ARM (fly ash, slag, rock pozzolan) consumption %	8.20	9.70	10.50	10.53	9.80	10. 5	10.30	11.40	9.66	10.15	10.56

Table 4.4 show examples of ARM with components contributing to the chemical composition of raw mix used at Lafarge (Sustainable Development Report of Lafarge 2010).

Table 4.4 Main Alternative Raw Materials consumed by Lafarge by 2010

Mill scale (Fe, Si, Al)	Petroleum contaminated soil (Si, Al)
Filter cake (element varies)	Bottom ash (Fe, Si, Al)
Cracking catalysts (Si, Al)	Water treatment sludge (Al, Si)
Blast furnace slag (Si, Fe, Al)	Fly ash (Fe, Si, Al)
Foundry sand (Si)	Refractory brick (Al, Si)

According to Lafarge Cement Works, three strategies have been adopted by the company (Schreiber 2007):

- Kiln efficiency improvement, which reduced emissions between 1990 and 2010 by 20%.
- Biomass and waste products usage as alternative fuels, which reduced CO_2 emissions throughout Lafarge cement plants by 30% since 1990.
- Waste usage as alternative raw materials or cement mineral additions, which reduced CO_2 emissions throughout the group's cement plants by 50% since 1990.

Replacing coal with plastic-derived and tyre-derived fuel from non-recyclable plastics and scrap tyres have been employed effectively in Lafarge. This approach has conserved natural resources and energy, and avoided landfilling of waste (Lafarge 2008). Furthermore, new minerals are formulated in the cement kiln giving cement its specific properties, the main components needed to produce cement being calcium carbonates, silicon, aluminium, and iron ore. Calcium is provided mainly by limestone, marl, or chalk. The silicon, aluminium, and iron components are provided by clay, shale and other raw materials. Specific quantities of raw materials are quarried by blasting to be crushed later on through the milling process (LafargeAggregates&ConcreteUK 2010).

At this stage, additional minerals are added to ensure the right chemical composition for cement. These can be obtained mainly from waste or by-products of other industries, such as paper ash, power station fly ash, silica fume, and blast furnace slag. Lafarge cement company has increasingly used alternative materials, rising from 8.20% in 2000 to 10.56% in 2010, to replace traditional raw materials in the clinker production process (LafargeAggregates&ConcreteUK 2010).

Significant environmental benefits have been achieved at Lafarge by using ARM, such as: reduction quarrying of traditional RM, natural RM conservation, reduction of energy consumption to produce cement, and reduction in the emissions of CO_2, GHGs, and dust (LafargeAggregates&ConcreteUK 2010). Chemical reactions occur at the kiln stage, the heart of the manufacturing process, when the raw meal is heated to 1500◦C to formulate the clinker which contains hydraulic calcium silicate. Traditionally, the key fuels used to heat the materials to this high temperature are coal, petroleum, coke, natural gas and oil (Lafarge-SR 2008), (LafargeAggregates&ConcreteUK 2010). In addition to use different types of Alternative types of fossil fuels such as: Solid waste, tires, liquid waste, waste oil, biomass, and animal meal with various percentages of substitution. The highest substitution was for using solid waste in 2009 and 2010 as shown in (Figure 4.3).

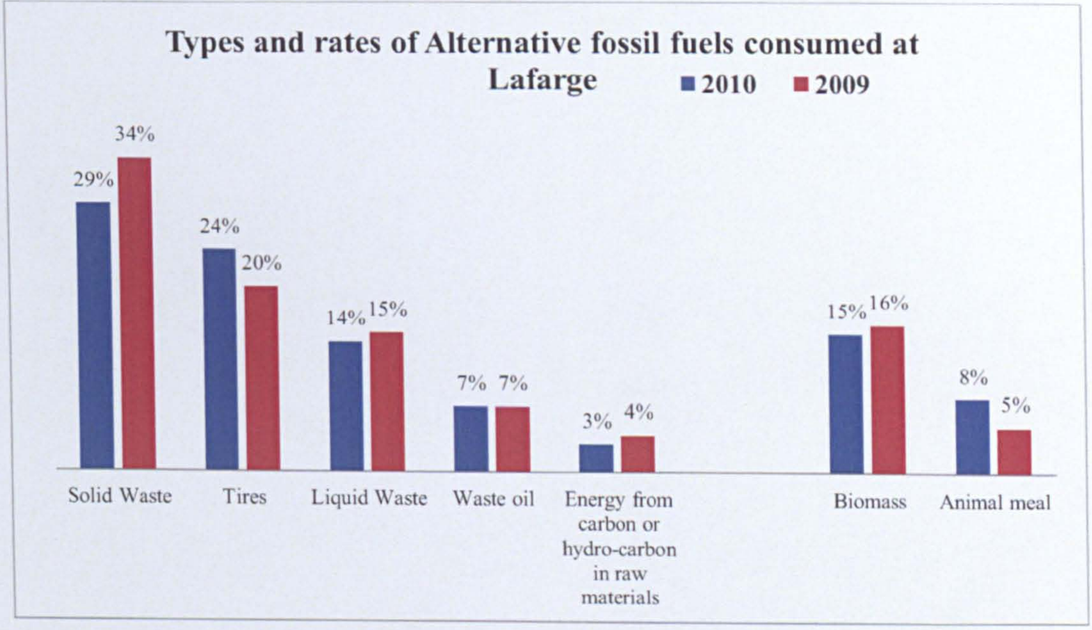


Figure 4.3 Types of alternative fuel used in cement plants in 2009 and 2010 as % of total alternative fuel use.

Figure 4.4 shows the thermal energy consumption of fuels at Lafarge which decreased in 2010 to reach 3.660 MJ/tonne clinker, declining from 4026 MJ/tonne clinker in 1990 to 3200–550 MJ/tonne clinker. The substitution rate of thermal energy consumed at Lafarge increased from 7.7% in 2000 to 12% in 2010.

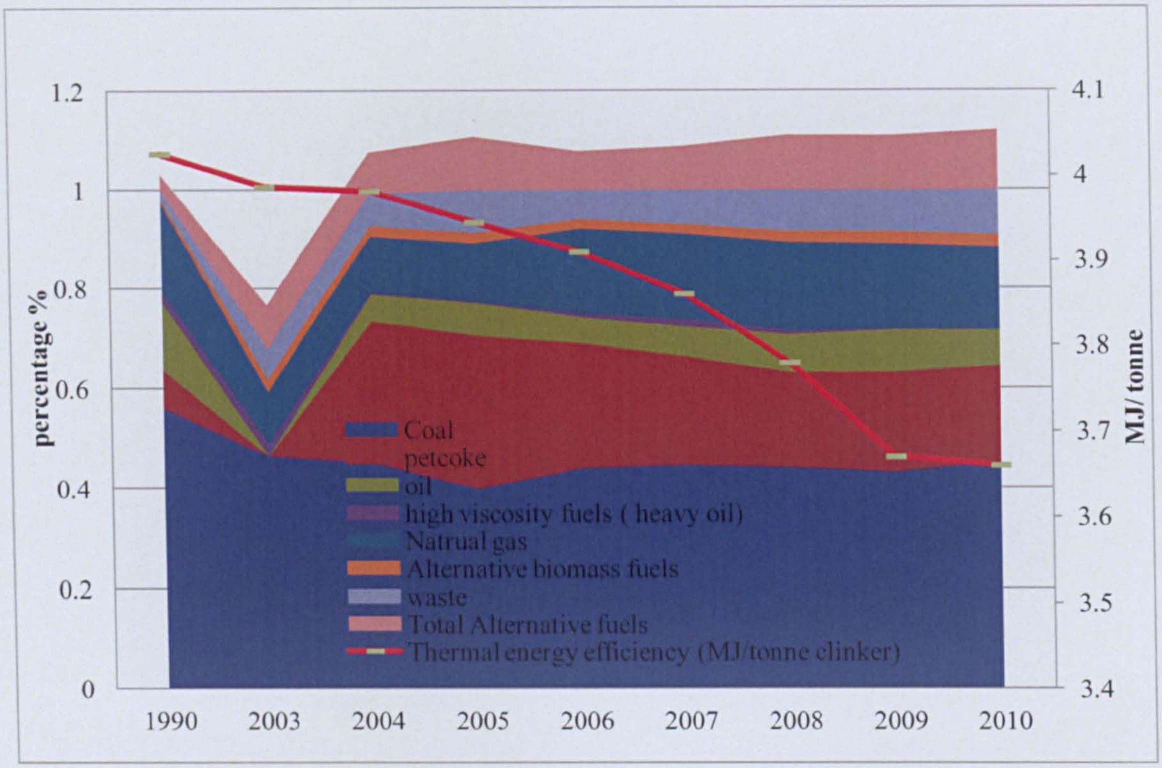


Figure 4.4 Improvement Trends of Thermal Energy Mix at Lafarge

At Lafarge the rate of AF usage has increased since 1990. Coal and oil usage has decreased, and usage of viscosity fuel has nearly disappeared, whilst gas usage, which has an emission factor 40% lower than that of coal, remains stable (LafargeAggregates&ConcreteUK 2010).

The combined effects of Lafarge's AFR usage led to the recovery of more than 7.3 Mt of biomass waste and by-products in 2008 and 8.1 Mt in 2010 (LafargeAggregates&ConcreteUK 2010). The use of further decarbonized additives such as fly ash, waste by-products of electricity generation, and blast furnace slag (a waste by-product of steel manufacturing) in the cement reduces the amount of clinker needed and hence the energy intensity of the product. The Lafarge cement company has achieved a 20% reduction in CO_2 per tonne of cement between 1990 and 2010, which corresponds to 606 Kg CO_2/tonne cement in 2010.

The type of AF varies with the nature of locally produced wastes. These wastes could be caused by carbon-neutral biomass such as palm kernel shells and rice husks, or industrial wastes such as tyres, bone meal, used oils, solid shredded waste, and solvents. In 2008 waste materials were utilized by Lafarge as alternative fuels by more than half of the company's cement plants. For example, in Brazil in 2007, 42% biomass and waste were utilized, reducing CO_2 emissions by 156000 tons. In France the fuels substitution rate reached 26% (Schreiber 2007).

Alternative fuels promote a reduction in resource depletion of valuable non-renewable fossil fuels. In addition to natural resource conservation, substituting various recycled waste materials such as blast furnace slag and pulverized fly ash, either as raw feed or as an addition to clinker, contributes to the reduction of specific CO_2 emissions.
Table 4.5 shows the percentage of different types used by Lafarge since 1990 to 2010.

Table 4.5 Fuel mix shares and usage in Lafarge for cement production(EuronextParis 2006).

Thermal energy mix of clinker production (%)	**1990**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Coal	56.10	46,57	45.30	40	44.20	44.80	44.30	43.40	45
petcock	7.60	26. 9	28.20	30.60	24.90	21.70	19.00	19.90	19.20
oil	13.50	4. 93	6.2	6.50	5.20	5,8	7.50	8.40	7.00
high viscosity fuels	2.10	2.59	0.30	0.30	0.70	1.50	0.70	0.10	0.10
Natural gas	18.10	10	11.50	11.90	17.20	17.40	17.90	17.20	16.60
Shale and lignite	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Others	1.19	0.15	0.37	0,05	0.0				
Alternative biomass	0.70	2.50	2.10	2.10	1.90	1.90%	2.30	2.60	2.70
waste	1.90	6.10	6.50	8.60	5.90	6.90	8.30	8.30	9
Total Alternative	3.00	8.60	8.30	10.70	7.80	8.80	11.00	11.00	12
Thermal energy		46,57		40		3860	3780	3670	3660

4.5 Carbon dioxide emissions at Lafarge between 1990 and 2010

Specific actions have been taken by Lafarge to contribute to the overall target for limitation of the rise in earth temperature, and a commitment has been made to meeting the ambitious objectives established within the framework of a pioneering partnership with the WBCSD as of 1999, in addition to Lafarge's commitment to partnership with the WWF as of 2001. In 2010 Lafarge made a significant advance in its fight against global warming through reducing its net CO_2 emissions by 21.7% compared to 1990. Figure 4.5 shows the overall net emissions which have been cut from 1 Kg/Kg cement (i.e., cement production was 100 metric tons of cement and net CO_2 released was 100 metric tons) to 0.78 Kg CO_2/ Kg cement in 2010.

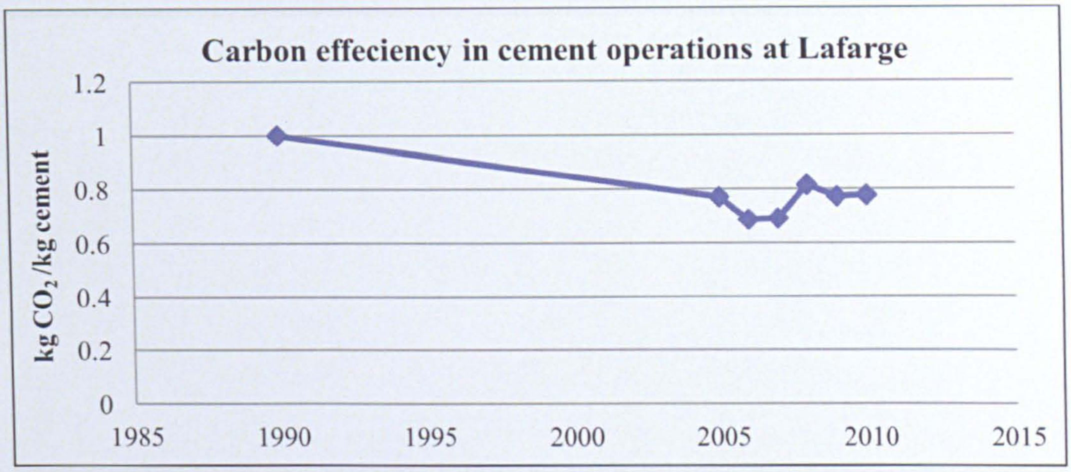


Figure 4.5 Trends in CO_2 net emissions from cement production at Lafarge between 1990 and 2010. Cement production increased by 53% from 1990 but CO_2 emissions increased by only 19% over the same period.

On another hand as shown in Figure 4.6, the CO_2 released from clinker burning was decreased by 17% in 2010 comparing to 1990 reaching 701 kg CO_2/ kg clinker in 2010.

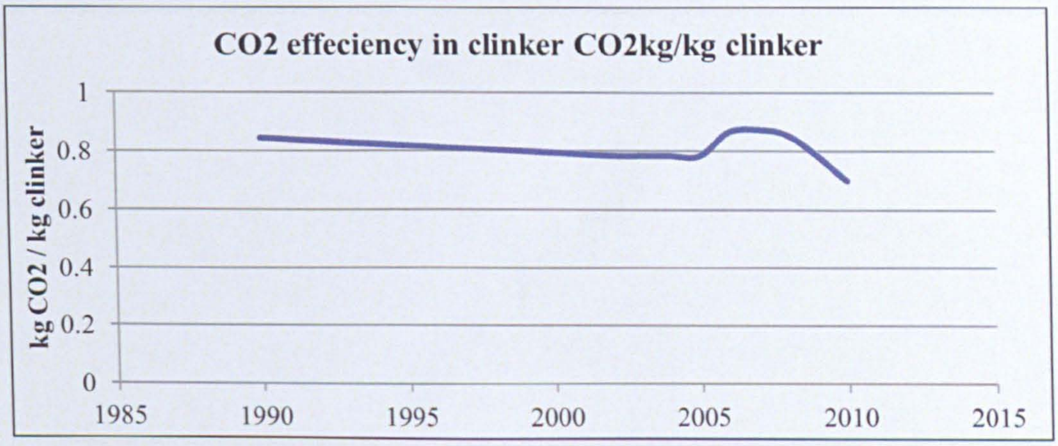


Figure 4.6 Carbon dioxide efficiency of clinker production at Lafarge in 2010 compared to 1990 levels (Kg CO_2/ Kg clinker).

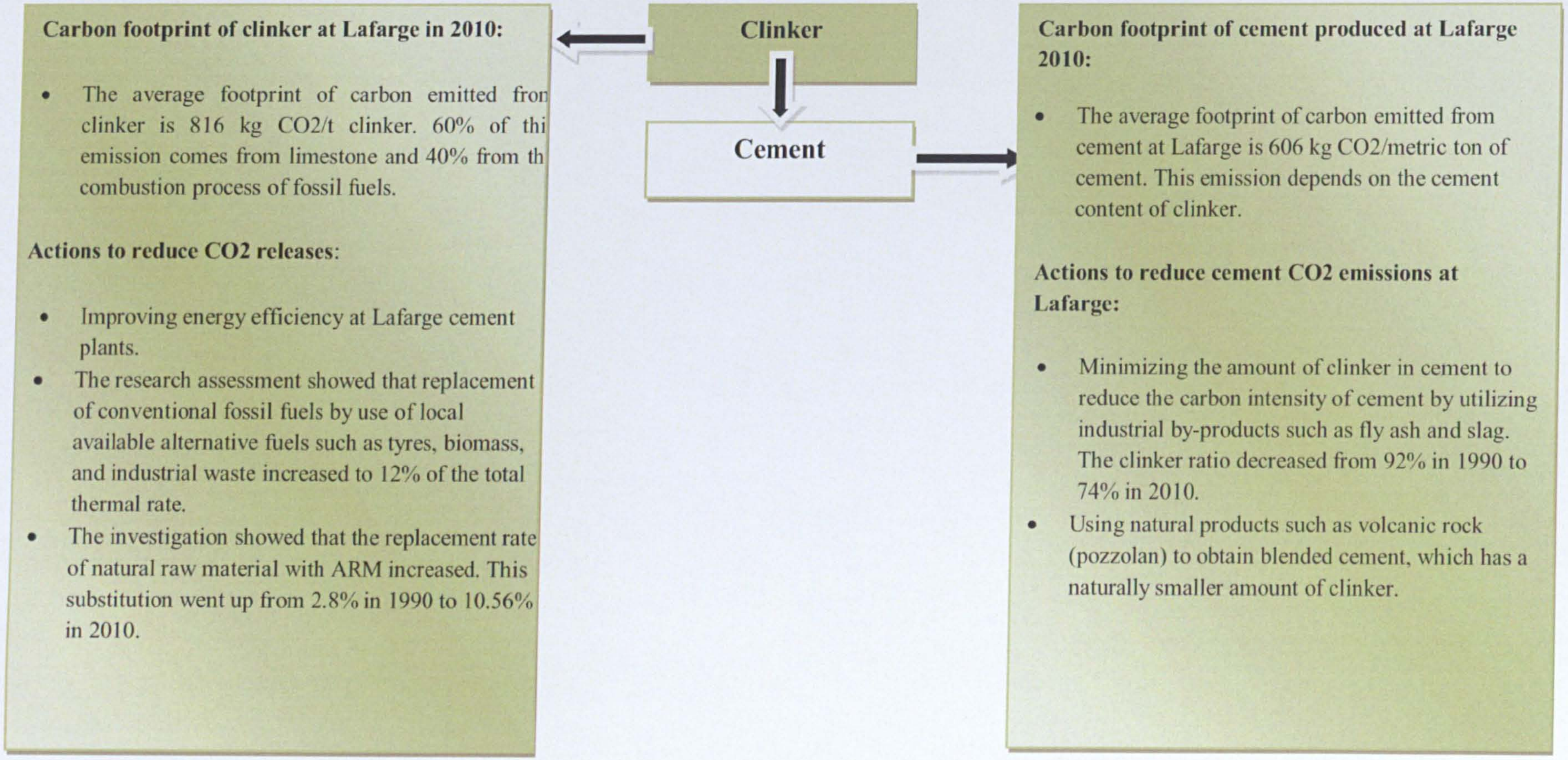
A number of development measures have contributed to CO_2 emissions reduction, including at Lafarge, such as reducing the specific heat consumption of Lafarge kilns and improving the old, less efficient plant by installation of up-to-date technology. A key contributor to energy efficiency is replacement of the specific rates from conventional fuels with those from alternative fuels such as biomass, waste, and by-products. 60% of CO_2 emissions in cement manufacturing result from the release of embedded CO_2 in limestone, a process called decarbonation; the remaining 40% comes from fossil fuel combustion to feed cement kilns, in which it is possible to utilize materials such as slag and fly ash.

CO_2 emissions have been significantly reduced by Lafarge in its cement operations and clinker burning. Specific procedures have been followed shown in (Figure 4.7), such as (Naik 2005):

- Improving energy efficiency and minimizing the overall energy consumption of cement plants at Lafarge
- Continuous upgrade of production plant facilities and technologies to improve the manufacturing process.
- Minimizing use of non-renewable energy sources by using AF and industrial waste throughout the manufacturing process.
- Modifying the chemical composition of clinker and minimizing the released CO_2 emissions by replacing specific raw materials which have carbon dioxide as main content with alternative materials such as slag and fly ash throughout the cement making process.

Table 4.6 shows the improvement and progress of specific levers affecting the reduction of CO_2 released by cement manufacture at Lafarge.

Indicators used to cut out CO_2 emission	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**	**1990**
Alternative raw materials consumption %	10.56	10.15	9.66	11.40	10.30	10. 5	2.8
Clinker factor (average % of clinker in cement)	74.00	75.00	76.00	77.00	78.00	79.00	92.00
Total Alternative fuels (%)	12	11	11	8.80	7.80	10.70	3
CO_2 Kg/Kg cement	0.78	0.77	0.81	0.69	0.68	0.77	1
CO_2 Kg/Kg clinker	0.675	0.785	0.875	0.875	0.786	0.785	0.845



Carbon footprint of clinker at Lafarge in 2010:

- The average footprint of carbon emitted fror clinker is 816 kg CO2/t clinker. 60% of thi emission comes from limestone and 40% from th combustion process of fossil fuels.

Actions to reduce CO2 releases:

- Improving energy efficiency at Lafarge cement plants.
- The research assessment showed that replacement of conventional fossil fuels by use of local available alternative fuels such as tyres, biomass, and industrial waste increased to 12% of the total thermal rate.
- The investigation showed that the replacement rate of natural raw material with ARM increased. This substitution went up from 2.8% in 1990 to 10.56% in 2010.

Carbon footprint of cement produced at Lafarge 2010:

- The average footprint of carbon emitted from cement at Lafarge is 606 kg CO2/metric ton of cement. This emission depends on the cement content of clinker.

Actions to reduce cement CO2 emissions at Lafarge:

- Minimizing the amount of clinker in cement to reduce the carbon intensity of cement by utilizing industrial by-products such as fly ash and slag. The clinker ratio decreased from 92% in 1990 to 74% in 2010.
- Using natural products such as volcanic rock (pozzolan) to obtain blended cement, which has a naturally smaller amount of clinker.

Figure 4.7 Actions to reduce CO_2 emission footprint at each step in Lafarge cement operations, these measures being in response to different actions and factors, not just one single action.

By following the previous procedures the amount of the net CO_2 released was 119 metric tonnes while the amount of cement production in 2010 was 153 metric tonnes (Figure 4.8) and (Figure 4.9).

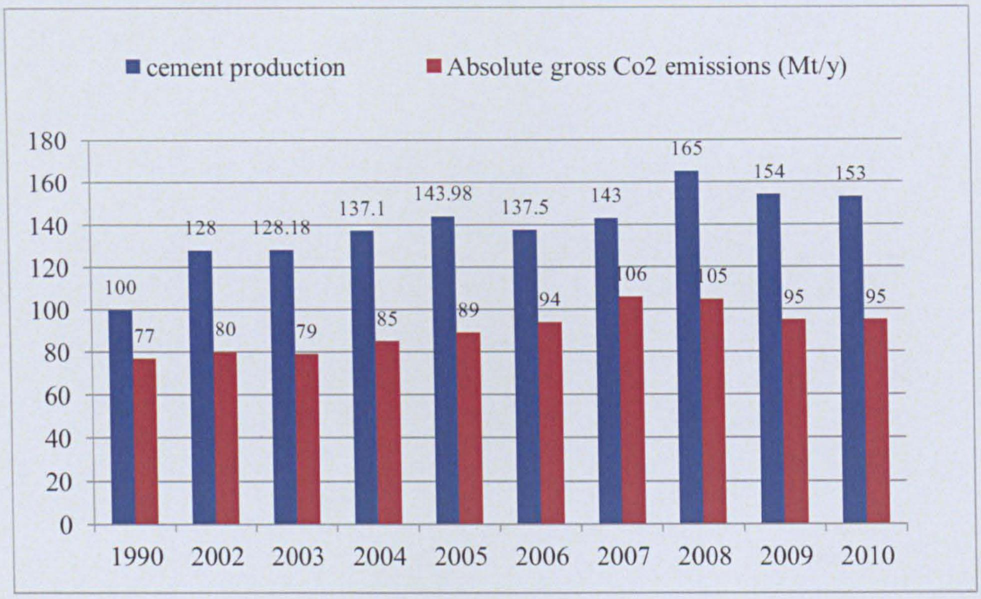


Figure 4.8 Levels of absolute CO_2 emission at Lafarge cement operations since 1990.

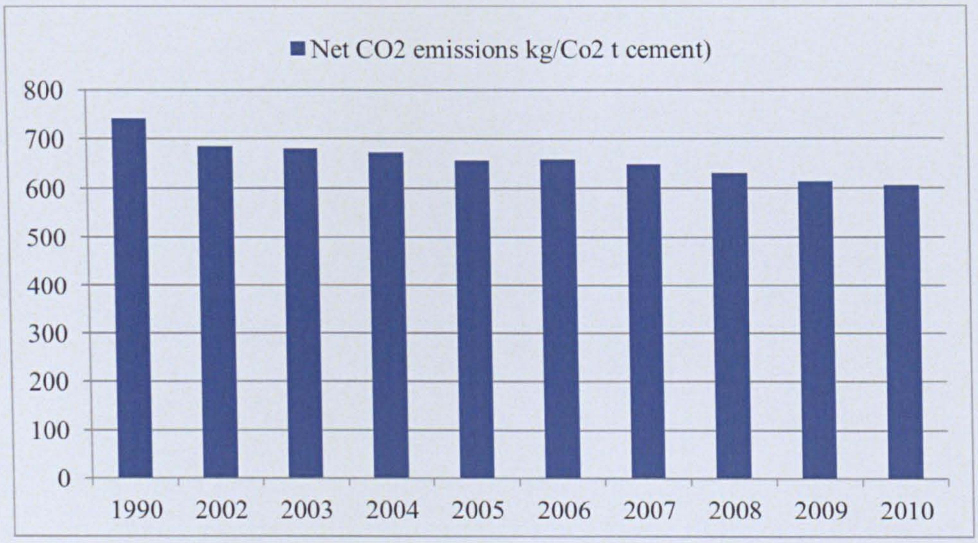


Figure 4.9 Levels of net carbon dioxide emissions (Kg CO_2/ per t cement) at Lafarge between 1990 and 2010.

However, Lafarge has concentrated on research into CO_2 emission reduction by investing 100 million Euros in Lafarge technical centres to increase energy efficiency at Lafarge cement plants (as stated by David Chrystall from Dunbar cement works) (Dunbarworks 2007). In 2006 the company launched an additional examination of CO_2 emission reduction techniques. This investigation concerns the cultivation of micro-algae which absorb the released CO_2 emissions from kilns, and are consequently used as biofuel.

4.6 Environmental impact assessment of the granted visit to Dunbar Cement Plant

Investigations were conducted among best performance cement companies in the world to benchmark the current status of the cement industry, and to examine qualitatively more sustainable materials, along with alternative methods and production technologies, for purposes of comparison.

Permission to conduct research based on plant data was granted during 2008 by the Dunbar manager, as the Dunbar plant is the only cement works in Scotland. It opened in 1963, with a capacity of one million tonnes of cement per year, and employing over 150 people. Benchmarking and trials took place.

4.6.1 Alternative fuels and raw materials used at Lafarge (Dunbar, UK)

Cement-making operations are one of the key focuses of Lafarge Cement's move towards sustainability. This emphasis is reflected in the drive towards creation of more energy-efficient products. In Blue Circle cement, 35% of the raw materials (30% crushed limestone, 5% gypsum) do not go through the kiln. This means that for each tonne of product, less energy is used and environmental emissions are lower.

(Figure 4.10) and (Table 4.7) show the amount of raw materials consumed by Dunbar cement works and the amount of CO_2 emitted, while (Figure 4.11) and (Table 4.8) show the amount of carbon emissions according to cement produced. These amounts were based on monthly rate.

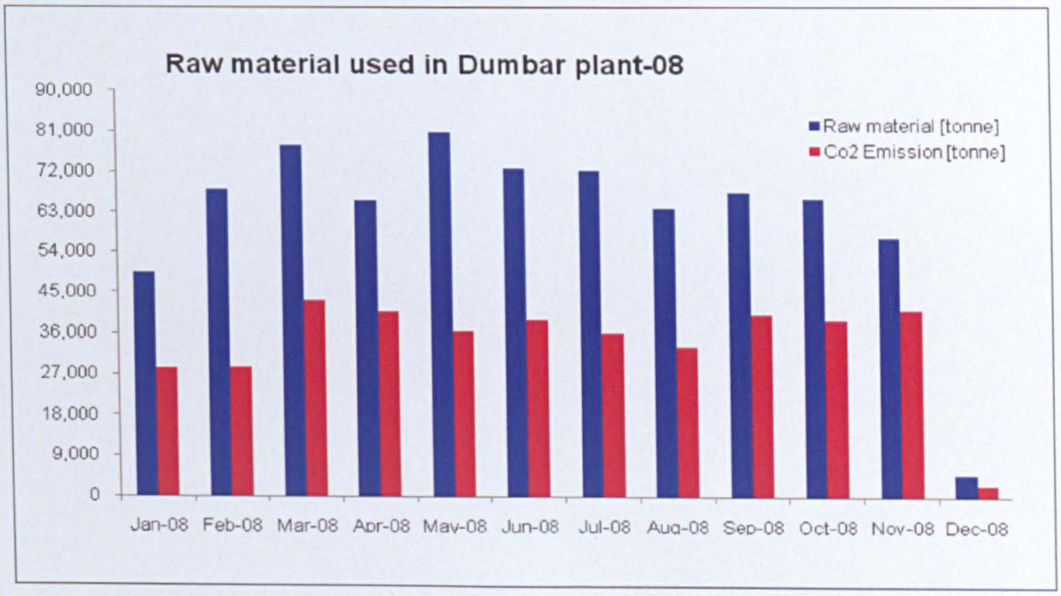


Figure 4.10 Used raw materials and their CO_2 emissions generated into atmosphere

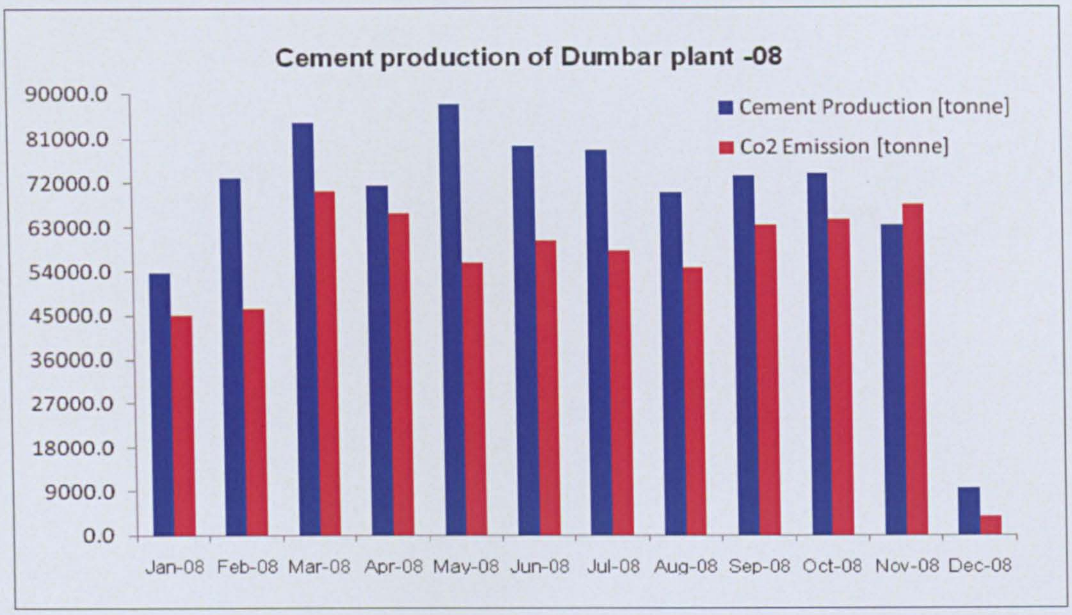


Figure 4.11 Dunbar cement production for 2008, and total CO_2 emissions into atmosphere: monthly data

Table 4.7 Amount of raw materials used and their emissions

Used raw materials and their emissions		
Month	Raw material [tonne]	Co_2 Emission [tonne]
Jan-08	49225.1	28324.0
Feb-08	68026.6	28465.2
Mar-08	77831.5	43036.6
Apr-08	65554.3	40773.3
May-08	80793.1	36690.1
Jun-08	72790.8	38939.2
Jul-08	72170.7	36217.8
Aug-08	63879.2	32996.3
Sep-08	67590.9	40276.3
Oct-08	66162.0	39092.1
Nov-08	57160.0	41089.4
Dec-08	5,091	2739.3

Table 4.8 Dunbar cement production and emissions for 2008

Month	Cement Production [tonne]	CO_2 Emission [tonne]
Jan-08	53618.1	45131.3
Feb-08	73050.4	46435.5
Mar-08	84410.9	70497.0
Apr-08	71450.8	65851.5
May-08	87834.2	55748.3
Jun-08	79428.3	60270.3
Jul-08	78492.6	58025.7
Aug-08	69958.4	54465.1
Sep-08	73310.6	63410.8
Oct-08	73640.0	64477.1
Nov-08	63449.0	67525.8
Dec-08	9,548	3915.2

Use of AFR such as scrap tyres also has a critical role to play. For example, scrap tyres have the same high-energy value as coal and have been used as a cement-making fuel worldwide for the last ten years. Each year in the UK more than 40 million tyres are removed from vehicles (cars and trucks). The disposal of these tyres is a major problem, which was set to grow when whole tyres were banned from landfill sites in 2003, and chipped tyres in 2006. But the cement kiln is considered ideally suited to help solve this problem by using tyres as a fuel. The tyres are used to heat the raw materials to temperatures in excess of 1000°C, which is hotter than molten volcanic lava. The environmental benefits gained from doing this include (Dunbarworks 2007):

- Reducing the factory's impact on the local environment
- Recovering energy from a product that would otherwise be thrown away
- Saving fossil fuels for future generations.

Other alternative fuels being used, or on trial at a number of works, include recycled liquid fuel, PSP (processed sewage pellets), meat and bone meal and packaging waste, as well as carbon-neutral biomass.

The fuels used at the Dunbar plant are coal (74%), tyres (14%), recycled liquid fluid (11%), and gasoil (1%). The emission factors for these fuels are 2.66, 1.8, 2.38, and

3.19 respectively. However, the main alternative fuels used are tyre chips and recycled liquid fuels.

4.6.1.1 Tyre chips

- Three million scrap tyres per year have been used at Dunbar.
- The tyres are collected from across Scotland, chipped on site and fed into the process to provide heat energy.
- Combustion at temperatures in excess of 900°C ensures that there is no black smoke or smell.
- The tyres are sourced and chipped by Sapphire Energy Recovery, a joint venture of Lafarge Cement UK and Michelin Tyre PLC.
- The tyres are fed into the process using an automatic system installed at a cost of 2 million pounds.

4.6.1.2 Recycled liquid fuel

RLF is a high-grade blended fuel made from non-recoverable materials used in making everyday products such as screen wash, paint, printing ink and brush cleaners. The fuel is blended to a strict specification set by the regulator for the works.

The content of RLF used at Lafarge Cement Works is monitored at every stage of its journey from the fuel blender to the factory. Samples are taken at three stages: when the fuel is blended, when it is loaded into the road tanker for delivery, and when it is unloaded at the works. Lafarge Cement Works are only allowed to use an alternative fuel if trials, authorised by the local regulator – the Environment Agency in England and Wales; the Scottish Environment Protection Agency in Scotland; and the Industrial Pollution and Radiochemical Inspectorate in Northern Ireland – show that using it has no overall detrimental impact on environmental performance.

The trials involve extensive gathering of emissions data for a specified period, using traditional fuels to establish baseline data, against which results from a period of alternative fuel usage can be assessed.

4.7 Wind energy potential in Dunbar Cement Works

The cement industry emits 5% of global CO_2 emissions, making the cement industry a crucial site of CO_2-emission mitigation strategies. CO_2 is released from the calcinations process of limestone, from combustion of fuels in the kiln, as well as from electricity generation.

The quantity of CO_2 emitted by the consumption of one unit of energy depends on the sort of fuel used. For instance, more CO_2 emissions are released from one unit of coal than from one unit of gas. Emissions per unit of electricity supplied by major power producers from fossil fuels are estimated at 614 tonnes of carbon dioxide per GWh in 2007 overall; within this figure, emissions from electricity generated from coal (911 tonnes of carbon dioxide per GWh electricity supplied) were around 2.5 times higher than those from electricity supplied by gas (366 tonnes of carbon dioxide per GWh). For all sources of electricity (including nuclear, renewable and auto-generation), the average amount of carbon dioxide emitted amounted to 505 tonnes per GWh of electricity supplied (Grimshne 2002).

Use of renewable energy is one of the solutions for reducing CO_2 emissions emitted by cement manufacturing. In the UK, wind energy is the most promising renewable energy resource, as Britain is considered the windiest area in Europe (CEMBUREAU 2006).

During the last two decades, interest in wind energy development has been growing worldwide. The major reasons for this increasing interest are the environmental damage caused by GHGs due to excessive consumption of fossil fuels; depletion of fossil fuel resources, predicted to last only 40 years; soaring oil prices in the international markets; insecurity of the supply of fossil fuels; incentives presented by wind energy; and the indigenous, abundant and environmentally friendly qualities of renewable energy resources (Dunbarworks 2007).

According to a World Wind Energy Association survey, good growth for the wind energy market can be expected despite the financial crisis. On the basis of data collected from 11 of the top 15 countries, representing over 80% of the wind energy market, the WWEA confirmed 5374 MW of newly installed capacity in the first quarter of 2009, equalling an increase of 23% over the previous year in the same countries (Figure 4.12).

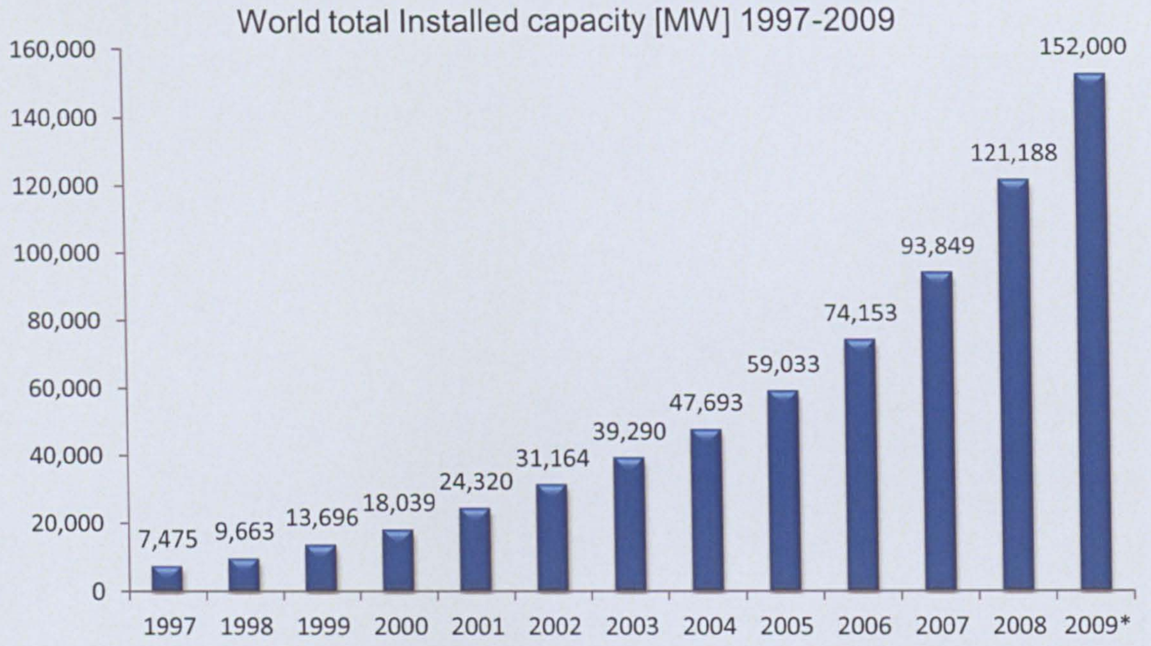


Figure 4.12 World wind turbine installed capacity between 1997 and 2009 (EWEA 2009).

Lafarge Company has experience of successful investment in wind energy, since a wind farm was installed in Morocco in 2005. At that time, Lafarge set up a 10 MW farm for the Tetouan cement plant as a Clean Development Mechanism (CDM) project, which enables the plant to reduce CO_2 emissions. Thus the company became the world's first cement maker to build a wind farm. This work investigates the feasibility of applying wind turbines as a means of offsetting the electricity demand of cement plants (Lafarge Dunbar works) within Scotland.

Regarding electricity consumption in all sub-manufacturing processes, the following tables: (Table 4.9) and (Table 4.10) show monthly consumption for each individual process for the year 2008 with cement production amount. The bill is subject to the plant's cement production and to electricity prices, since all the plant's electricity demand is met by the grid.

Table 4.9 Breakdown of electricity consumption for each single stage of the cement manufacturing process at the Dunbar works.

Electricity consumption of Dunbar Cement Works for 2008

Unit is MWh	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Primary raw materials	403	414	308	385	356	318	315	346	335	368	306	198	4049
Raw meal	1934	2148	2895	2709	2589	2702	2604	2638	2612	2656	2336	156	27977
Burning	3543	3866	4885	4690	4295	4525	4532	4280	4358	4569	4178	509	48228
Grinding	2823	3737	4576	3914	4584	4369	4162	3671	3788	3628	3287	1646	44182
Filling and Loading	282	294	285	316	342	316	322	323	361	259	258	304	3662
General	142	135	138	119	106	90	93	93	93	122	133	154	1419
Total	9126	10593	13086	12132	12271	12319	12027	11350	11546	11602	10497	2967	129516
Cost £	967367	1122837	1387116	1286024	1300726	1305782	1274873	1203121	1223865	1229833	1112724	314481	13728738

Table 4.10 Monthly cement production with electricity consumption plus its cost.

Electricity consumption relative to cement in production, Dunbar works 2008.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Total cementitious products [Tonnes]	56623	57667	86818	81579	75383	79250	73428	67403	80574	80131	82654	9548	831057
Electricity consumption [MWh]	9126	10593	13086	12132	12271	12319	12027	11350	11546	11602	10497	2967	129516
Total Cost (£*1000)	967	1123	1387	1286	1301	1306	1275	1203	1224	1230	1113	314	13729

4.7.1 Proposed wind farm for Dunbar Cement Works

Numerous factors affect the price and rent for large-scale wind turbine facilities. The basis of payment is developing and changing as the technology establishes itself. For the present feasibility study on erecting a wind turbine for Dunbar cement plant, advice was sought from a professional land surveyor (Mr. I.murning) who has estimated a basic rent of £1,000 to £5,000/annum per turbine with an additional payment to the landlord (farmer) of 5% to 10% of the gross revenue produced from the sale of electricity to the national grid. Presently within Scotland there are wide variations in the rent and/or royalties payable to a landlord depending on the location, windiness, access, infrastructure costs, negotiating strengths of the parties and so on. For the present study's purposes, the higher figures of £5,000 per annum rent per turbine and 7.5% of gross estimated annual revenue from the sale of electricity to the grid have been assumed.

In 2007 the German wind energy market was the biggest in Europe. Two manufacturers control the market: Enercon with a market share of 50% and Vestas with 24%. In this study, the economics of four potential machines have been explored – one of German make, the Fuhrland FL1250 machine and one of Danish design, the Vestas V90 wind turbine. In addition, the hourly wind speed data measured by the UK Meteorological Office was obtained from a windy location, relatively close to the plant's location on the seaside.

4.7.2 Wind resource assessment and wind turbine modelling

Evaluation of wind energy potential in the candidate site has been performed using data from the British Atmospheric Data Centre (BADC). The data used were the hourly rates for wind speed and direction; depending on that, the wind speed monthly average has been calculated and the annual wind rose of the Dunbar site compared with the wind rose of the Edinburgh airport site as shown in (Table 4.11) and (Figure 4.13).

Table 4.11 Monthly average wind speed for candidate location.

Month-2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean wind speed m/s	7.45	7.18	7.37	4.97	4.01	4.55	3.93	3.94	6.03	4.67	6.02	5.6

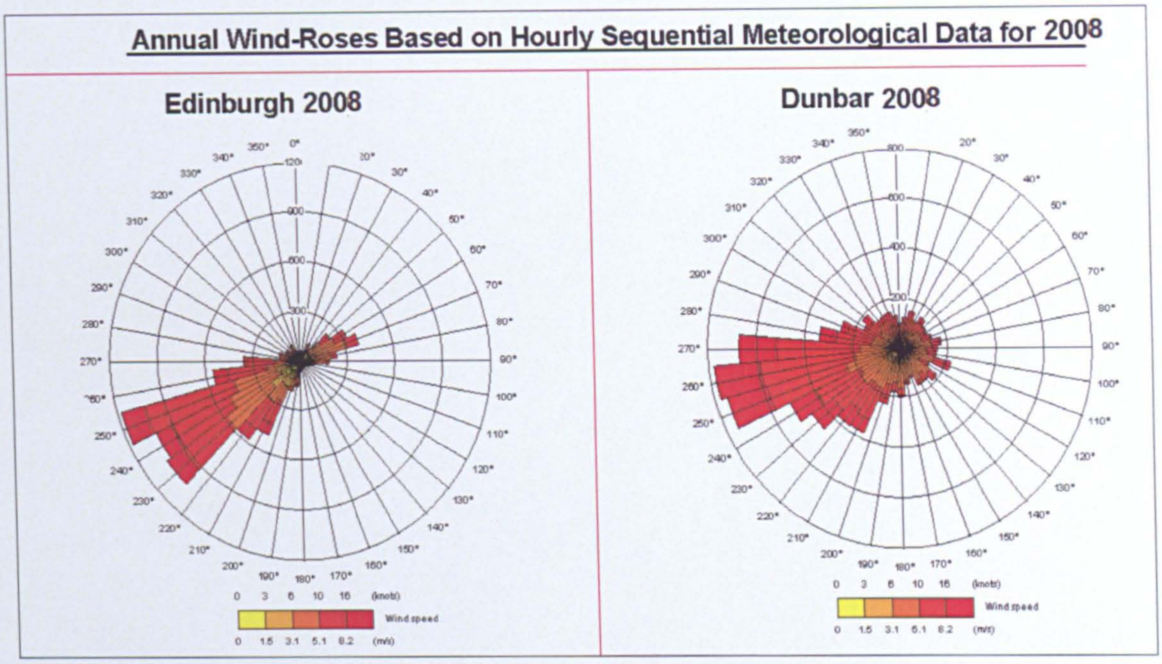


Figure 4.13 Wind roses for Edinburgh city and Dunbar location.

The results of the present analysis are provided in Table 4.21. The Fuhrland Model FL 1250 wind turbine seems to provide the fastest payback and therefore from an economic point of view it would be the logical choice. The following assumptions have been made in constructing (Table 4.12): electricity sold to grid at 7 pence/kWh (present-day cost), with expected inflation of 40% in the next 3 years; royalty payment to farmer of 7.5%; and maintenance contract payments of 0.095 pence/kWh from electricity sales.

Table 4.12 Performance of the chosen machines for the site under consideration.

	Fuhrland Model FL 1250	Vestas Model V90
Rated power, MW	1.25	3
Mean wind speed for the site m/s	5.5	5.5
MWh produced/annum	2209	5532
Capacity Factor	0.2	0.21
Machine cost, Million £	0.71	2.8
No. of machines to meet 100% of demand	59	24
No. of machines to meet 12 % of demand	7	3

Table 4.13 Economics of wind energy for the chosen machines.		
Type of wind turbine	Fuhrland FL1250	Vestas V90
Machine cost, million Euro	0.9	3.5
Machine cost, million £	0.71	2.8
Number of machines	7	3
MWh produced/annum	15463	16596
Electricity sales revenue	£1,515,374	£1,626,408
Site rent to farmer	£35,000	£15,000
Royalty to farmer from electricity sales	£113,653	£121,981
Maintenance to wind turbine manufacturer from electricity sales	£146,899	£157,662
Net savings/annum	£1,219,822	£1,331,765
Payback, years	6	7

As shown in (Table 4.13), it was found that the Fuhrland 1.25MW machine provides the fastest payback (6 years) from an economic point of view. The capacity factor for this machine, to be located on the eastern coast of the plant, will be around 0.20. The machines will be able to offset 12% of the total electrical load for the Dunbar works; this wind farm will consist of 7 wind turbines as shown in (Figure 4.14)and will reduce emissions of CO_2 by 10000 tonnes a year.

Figure 4.14 The suggested location for the three Vestas V90 wind turbines at Dunbar cement works.

4.8. Result and conclusion

The specific topic of this study relates to emission mitigation options for the cement industry, energy efficiency improvement, a shift to low carbon fuels, application of waste fuels and types of alternative raw material that can be used beneficially, increased use of additives in cement making, and indicators for evaluating environmental performance in response to the WBCSD initiatives.

It has been found as shown in (Table 4.14) that reduction of CO_2 emissions in cement production is achievable by decreasing the clinker percentage in cement, decreasing the consumed percentage of raw materials, and improving the efficiency of fuels burnt throughout the process of cement manufacturing. Since the utilization of waste has offered a new approach for cement production and energy conservation, a beneficial new product has entered the cement market, together with new recycling technologies which have saved valuable fossil fuels for future generations and reduced CO_2 emissions associated with fuels combustion and raw materials calcinations by 9% in 2010 comparing to 1990.Carbon reduction from clinker and Calcination was around 13.87%. The total emissions saving was 22.87%

Table 4.14 CO_2 emission saving rate at Lafarge Cement Group over the period 1990–2010.

CO2 saving from using alternative raw materials kgCO2/kg cement	4.87%
CO_2 saving from clinker reduction	13.87%
CO_2 saving from AF	9%
Total CO_2 emissions saving $kgCO_2/kg$ cement	22.87%

The technology for recycling industrial by-products has been well proven in cement production in the European cement industry in general and in Lafarge cement operations in particular. The utilization of by-products such as rice-husk ash, silica fume, coal fly ash and slag at Lafarge has helped to reduce the CO_2 released worldwide by the company. Emissions of CO_2 were cut by 22% in 2010 compared to 1990, representing a total mitigation of 25 million tonnes of CO_2 equivalent per year; and by 38% in absolute CO_2 terms compared to 1990 levels in developed countries. There was also a decrease in the clinker factor from 92% in 1990 to 74 % in 2010, which improves air quality, minimizes solid waste, and contributes to the sustainability of cement production. The reduction performance combines the intensive use of mitigation levers including: savings from using ARM, savings from clinker production reduced, and savings from AF.

Lower energy consumption, as a factor of equal or greater energy efficiency, contributes to environmental protection and economic progress as perspectives within the triangle of sustainability. When less energy is used, less is generated by power plants, thus reducing energy consumption and production. At Lafarge the energy consumed in 2010 was 12% below 1990 levels. This in turn saved 8.75% of the CO_2 released to the air worldwide in 2010.

Tarun R. Naik and Moriconi have urged: "Obey the rules of nature: use only what you need and never use a resource faster than nature can replenish it; that we cannot create or destroy matter, we can only affect how it is organized, transformed, and used. The issue is not environment vs. development or ecology vs. economy; the two can be (and must be) integrated" (EuropeanWindEnergyTechnologyPlatform 2006).

Table 4.15 summarised the assessment of Lafarge's performance. It has been found that sustainability in cement production was achieved by: using and producing less clinker, consuming less water throughout the cement manufacturing process, approaching a specific high quality process, using minerals and additives that keep the chemical admixture of clinker but reduce the emissions released, and conserving natural resources by replacing 10.56% of raw materials with slag and fly ash. At Lafarge cement works CO_2 emissions declined by 5% in 2010.

Therefore, cement production at Lafarge has provided unique benefits to the environment, through saving 23% of natural resources (RM, fuels, water, and industrial by-products) by waste recovery technology and environmentally sustainable waste management, and to society by offering long-term solutions for the treatment of waste produced by human activities. In addition, the economy has profited by savings equal to 27 Euro/tonne cement/year, through the cost-effective replacement of natural resources consumed by the cement making process at Lafarge.

Table 4.15 Environmental performance assessment of Lafarge Cement Production from 1990 to 2010.

Indicators used to assess Lafarge's environmental performance	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**1990**
Absolute gross CO_2 emissions (Mt/y)	95	95	105	106	94.4	89.3	85.2	79.5	80.8	77.8
Emissions related fossil waste fuels (Kg/tonne cement)	18	18	16	17.2	18	17	15	15	12	6
Cement production (million metric ton/y)	153	154	162	148.8	131	131	108.535	101.27	102.92	100
Clinker factor (%)	74	75	76	77	78	79	80	79	80	84
Alternative biomass fuels (%)	2.7	2.6	2.3	1.9	1.9	2.1	2.1	2.5	2.1	0.70
Waste utilization (%)	9	8.3	8.3	6.9	5.9	8.6	6.5	6.1	6.1	1.90
Total AF (%)	12	11	11	8.8	7.8	10.7	8.3	8.6	8.3	3
Alternative raw materials (Resource conservation) (%)	10.56	10.15	9.66	11.4	10.53	10.5	9.8	10.53	10.5	1.6
Water consumption (L/t)	479	481	343	343	355	379	383	366	427	412
Quarries with rehabilitation plan (%)	84.50	79	79	75	79	71	71	70	65	56

Chapter 5

Case Study for Holcim Cement Corporation Worldwide

5.1 Holcim Cement Operation

This chapter, a case study of Holcim, will assess the environmental impact of Holcim's performance from 1990 to 2010, particularly regarding emissions of CO_2. This investigation has been conducted through major activities including the setting up of specific EPI in association with the WBCSD initiative, and visiting the highest quality cement plant, "Siggenthal plant in Zurich". This visit was authorised by the Environmental Department director Mr David Kingma (Holcim-Zurich 2009).

Figure 5.1 shows the improvement trends of cement production at Holcim.

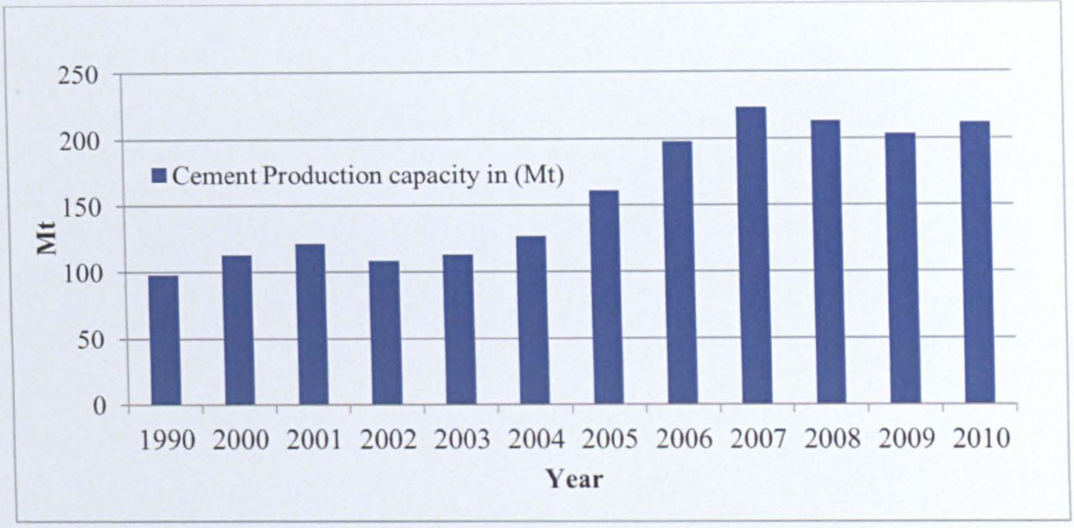


Figure 5.1 Development of cement production at Holcim between 1990 and 2010 (Mt).

The objectives of the research for Holcim are to investigate the ways used by Holcim to meet the sustainability challenges of:

- Reducing the ecological footprint related to waste recycling, quarry rehabilitation, and water consumption, taking into account the accessibility of the required data
- Making efficient use of natural resources including energy and raw material consumption
- Identifying the main levers for reducing the CO_2 emissions released throughout the process of cement production
- Assessing the environmental performance impact over the last twenty years by using the benchmarking tool at the company level.

In this regard, current practice at Holcim will be reviewed by this research and compared to the best practice of other cement companies (Lafarge and Taiheiyo), so as to construct a framework and identify tools for developing SD best practices and implementation, with special reference to the environmental perspective and CO_2 emissions.

5.2 Holcim and sustainable development

Increasing concern with the effects of economic development on health and natural resources led Holcim to recognize the need for a sustainable development approach in the company's cement operations, considering the responsibility for natural stewardship and human financial resources, and the need to change and modify the process of cement manufacture (Holcim-Publications 2009) to ensure the best fit with the built environment throughout. It has committed itself to international organizations such as the WBCSD, of which Holcim is considered a co-founder.

Mr David Kingma explained in his interview the main perspectives of Holcim's environmental policy for SD, as summarized in the following points:

- Applying the SD triple bottom line for a healthy, prosperous, and stable life through practical and balanced operations.
- Integrating sustainability application of "green" or environmentally responsible practices into the process of facility delivery from the very beginning.
- Recognizing that sustainable practices are an investment in the future, to be pursued through conservation, improved maintainability, recycling, reduction and reuse of waste.

Figure 5.2 shows measures to reduce CO_2 emissions from the environmental perspective of the Sustainable Development triple bottom line, inasmuch as the eco-efficiency approach improves environmental, economic, and social performance.

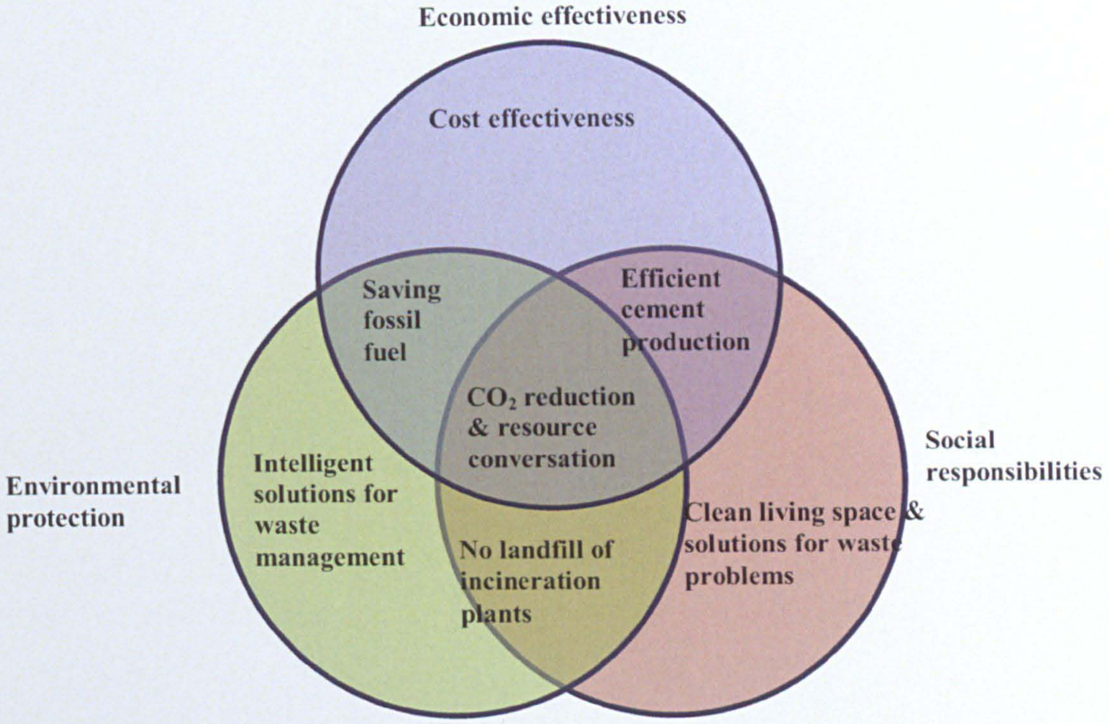


Figure 5.2 The Sustainable Development perspectives in Holcim's cement operations (Holcim-publicatio 2006).

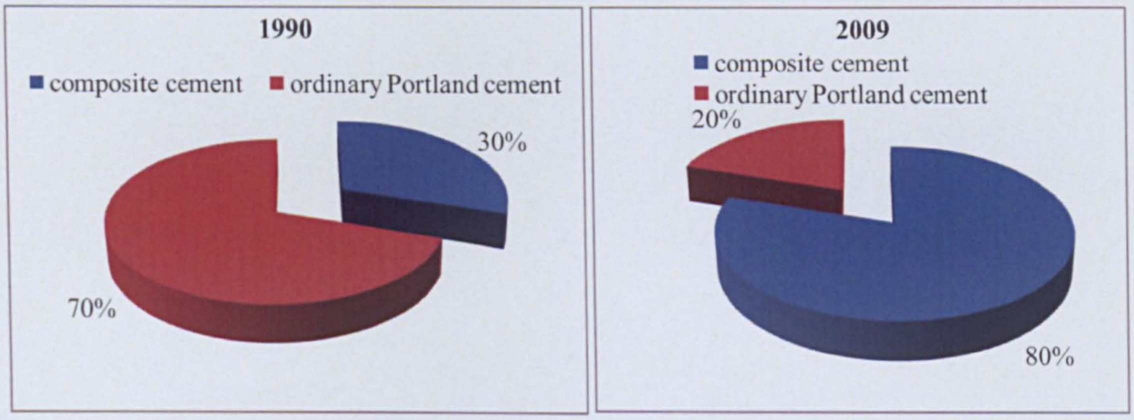
A target was set by Holcim as part of its commitment to the WBCSD (Holcim-publications 2003) to reduce specific net CO_2 emissions by 20% in 2010, using 1990 as a reference year. The achievement of this reduction will be assessed by this research according to main eco-efficiency parameters, including: clinker factor, specific thermal energy consumption, thermal substitution rate, limestone and raw materials substitution rate.

The investigations showed that Holcim promoted and increased the production and usage of sustainable, eco-efficient products, such as composite cements which contain mineral components, from 1990 to 2009. The mineral components are cement constituents that are not derived from clinker production. These minerals include blast furnace slag from steel manufacture, fly ash from coal-fired power generation, and natural pozzolan and limestone. Table 5.1 shows the different types of cement produced by Holcim Cement Company from 1990 to 2009.

Table 5.1 Types of cement produced at Holcim

Types	1990	2005	2007	2008	2009	2010
Slag cement %	2	8	10	11	9	9
Pozzolan cement %	3	9	7	8	9	9
Fly ash cement %	1	3	19	23	26	26
Limestone cement %	20	16	12	15	14	13
Multiple blended cement %	2	16	21	17	17	16
Masonry cement, oil well cement, white cement	70	5	4	4	5	4
Ordinary Portland cement %	2	40	25	22	20	23
Other cementitious materials		3	2			

In 1990 cement composite constituted 30% of Holcim's total cement production. The proportion of this composite cement increased to 60% in 2005 and 80% in 2009 (Holcim-Publications 2009), Figures 5.3 (a) and (b).



Figures 5.3(a) (left) and 5.3(b)(right) The Production Rates of OPC at Holcim Source: presentation of SD report of 2009 (Holcim-Publications 2009)

The role of the increasing share of composite cement, recycled materials, and the growing amount of waste-derived fuel used in Holcim kilns to develop eco-efficient cement products, energy improvement and process efficiency will be assessed later in this chapter.

5.3 Environmental performance assessment of Holcim

Producing cement by eco-efficient processes is the main requirement of sustainable cement production. This will be achieved by reducing the intensity of inputs resources such as natural raw materials and energy consumption, and producing less waste and pollution per tonne of cement (WBCSD&IEA 2009). Fundamental indicators have been set to measure the environmental performance of Holcim's cement production from 1990 to 2010, including assessment of:

- Resource conservation: water management, limiting and recycling waste (waste recovery), natural raw materials, and energy consumption.
- Quarry management and rehabilitation.
- Atmospheric emissions with special reference to CO_2 emissions, and tools used for reducing this emission.

5.3.1 Limiting and recycling waste

Based on the GIZ and Holcim partnership publication's waste management module, a definition of waste has been set as: "Any substance or object, which the holder discards or intends or is required to discard or has to be treated in order to protect public health or the environment".

The distinction between "waste for recovery" and "waste for disposal" must be noted as shown in (Figure 5.4):

- Waste for recovery is waste that will be recycled for material or thermal use.
- Waste for disposal is waste that will be disposed of (landfill, incineration).

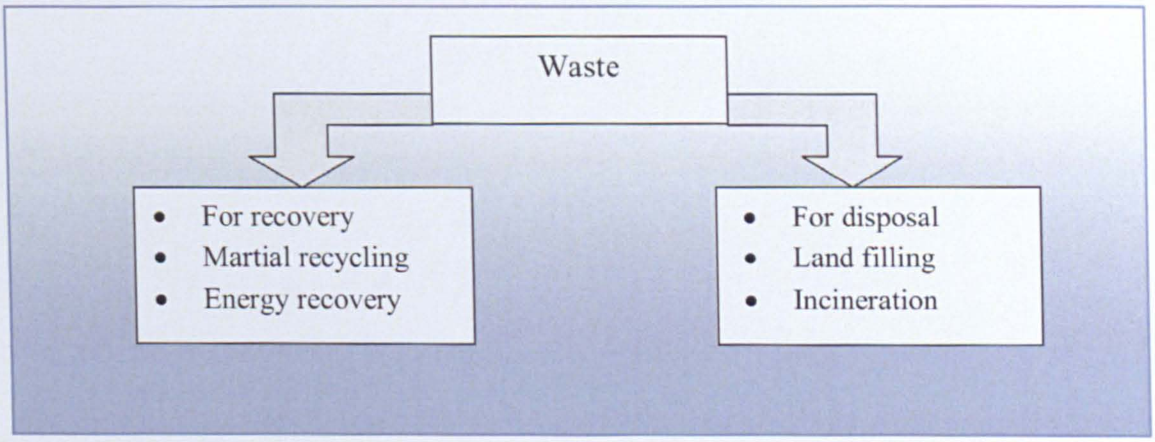


Figure 5.4 Summary of waste definitions.

The potential of waste usage as AFR was reviewed at a pre- or co-processing site within Siggenthal cement plant. This requires a careful selection process operated by the plant sites and associated directly with the next steps in the cement production process. The waste usage process at Siggenthal Holcim consists of the following steps:

- Identify origin of candidate waste.

- Evaluate type of waste generation process, intermediate disposal, waste treatment and storage, fiscal and chemical characteristics of the waste, and hazard classification.
- Check the existing volumes of stock waste. Handling of wastes and AFR shall be done in such a way as to prevent the possibility of spills and groundwater/ soil contamination, and to minimize odours and noise.
- Test a representative waste sample including characteristics listed in the operational permit and in the plant specifications.

Co-processing means the replacement of conventional fuels (coal, petroleum, gas), and raw materials by waste, thus recovering energy and material from waste. Waste materials used for co-processing are referred to as alternative fuels and raw materials (Morf 2007). Table 5.2 clarifies the usage types of waste materials (as raw materials, source of energy or both) to replace natural mineral resources and fossil fuels in the manufacturing process of cement production.

Table 5.2 According to GIZ modules 1 and 8 (2011), replacing the conventional fuels and raw materials in co-processing achieves the following points which appear in (Figure 5.5):

Table 5.2 Types of waste materials and its usage at Holcim

Waste	Substitution	Examples
Energy Recovery: Energy content(Carbon, hydrogen)	• Substitution of fossil fuel energy	• Solvents • Waste Oils • Waste plastics
Material Content: Material content (CaO, Fe2O3, Al2O3, etc) **Energy Recovery**: Energy Content(Carbon, hydrogen)	• Substitution of raw material • Substitution of fossil energy	• Used tires • Used paints • Industrial sludge
Material Recycling: Material Content(CaO, Fe2O3, Al2O3)	• Substitution of raw material	• Molding sand • Blast Furnace Slag • Fly Ash and Bottom Ash • By product gypsum

- Conserve non- renewable resources of natural energy and raw materials. Accordingly, minimize dependence on markets of primary resources.
- Minimize the environmental impact and pollution resulting from raw materials extraction and burning.
- Reduce GHG emissions in order to decelerate global warming .
- Save landfill used for waste disposal.
- Minimize the environmental impact resulting from mining, quarrying, transportation, and raw materials processing.

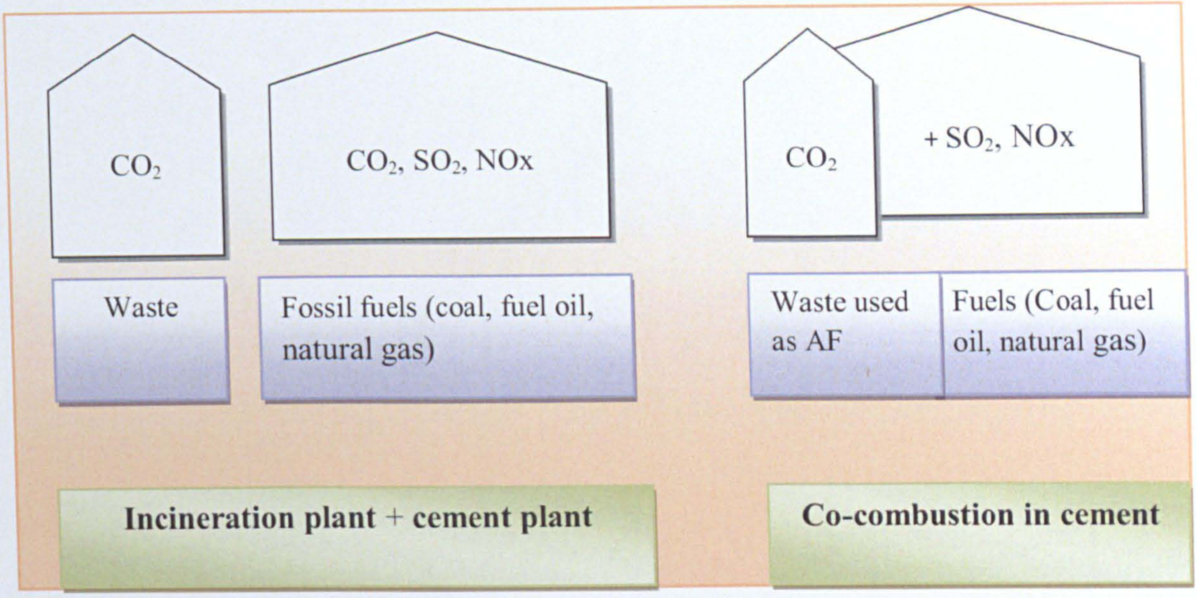


Figure 5.5 Waste recovery by cement operations at Holcim and benefits of co-combustion of alternative fuels in the cement industry (Ashley Murray 2008).

The types of waste material used by Holcim are identified on the basis of waste origin (industry, agriculture, mining etc.). They can be solid, liquid, or ashy and include the following types:

- Municipal waste (household waste, commercial waste)
- Construction and demolition waste
- Industrial waste (non-hazardous industrial waste, hazardous industrial waste)
- Waste from health care facilities (clinics, hospitals)
- Sewage sludge (wastewater treatment)
- Agricultural waste.

5.3.2 Energy Consumption at Holcim

The investigation showed that the improvement of energy efficiency at Holcim has had the combined effects of shifting away from inefficient wet kilns to dry kilns, as well as using less energy-intensive equipment and practices. In addition, Holcim has employed advanced technology which has reduced consumption of energy and raw materials in 2010 compared to 1990. Figure 5.6 shows the improvement tendencies of the thermal energy mix over the last twenty years at Holcim. The thermal mix consists mainly of coal, petcock, heavy fuel, natural gas, shale, alternative fossil fuels and biomass. A percentage of biomass utilization as a source of neutral carbon energy, replacing natural fuels at Holcim, is playing a key role in reducing CO_2 emissions. Although the improvement in the rate of biomass consumed at Holcim did not increase a great deal between 2000 and 2010, this rate is significantly high in comparison with other cement companies (WBCSD- GNR 2006). The biomass consumption at Holcim rose from 1.7% in 2000 to 2% in 2010.

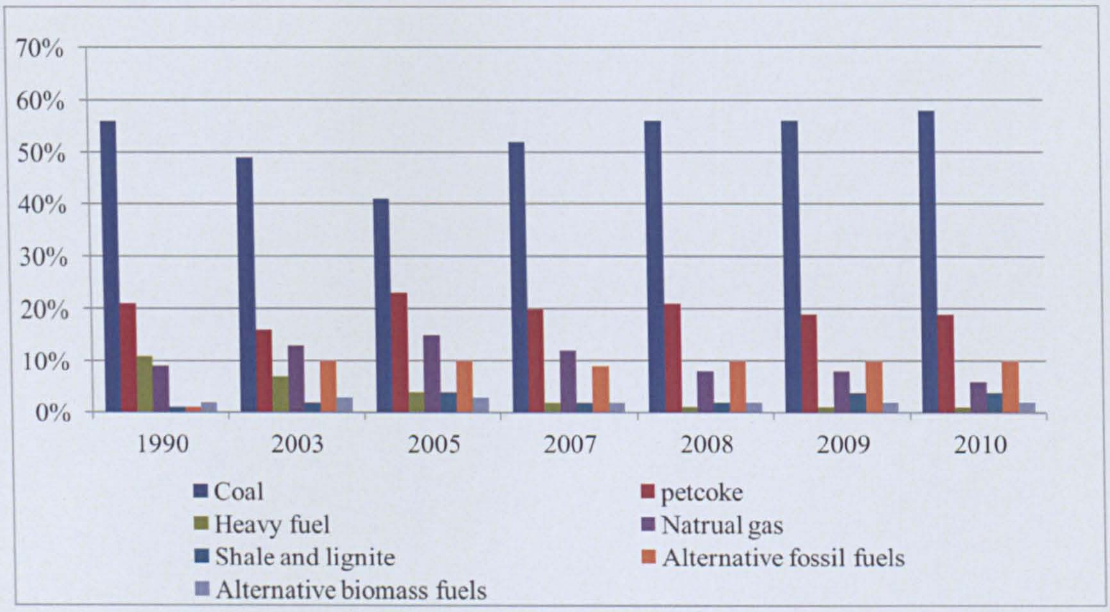


Figure 5.6 Improvement of thermal energy mixed to produce one tonne of clinker (1990–2010).

Table 5.3 shows the thermal mix improvements at Holcim of alternative fossil fuels and biomass since 2002 until 2010.

Table 5.3 Improvement trends of waste recovery at Holcim	2002	2005	2007	2008	2009	2010
Waste oil	0.12	0.10	0.08	0.08	0.08	0.08
Used Tires	0.13	0.15	0.17	0.16	0.15	0.13
Plastics	0.02	0.07	0.11	0.12	0.13	0.13
Solvents	0.17	0.16	0.12	0.11	0.10	0.11
Impregnated sawdust			0.09	0.08	0.10	0.09
Industrial waste and other fossil-based wastes	0.13	0.20	0.27	0.27	0.27	0.28
Animal meal and animal fat	0.10	0.06	0.04	0.03	0.03	0.02
total biomass consumed	0.23	0.26	0.12	0.15	0.14	0.02

Thermal energy consumption at Holcim improved in 2010, going down from 4544 MJ/tonne clinker in 1990 to 3940 MJ/tonne clinker in 2000, to achieve more efficient consumption in 2010, reaching 3555 MJ/tonne clinker. Energy consumption was reduced by 10% in 2000 compared to 1990 levels and 21.17% in 2010 compared to 1990. These results have been summarised in (Figure 5.7). Decreasing thermal energy consumption is an important method of reducing the emissions of CO_2 released from the combustion process, especially since the rate of CO_2 emissions coming from the burning of fuels accounts for 40% of the total released CO_2 (Ernst Worrell 2001).

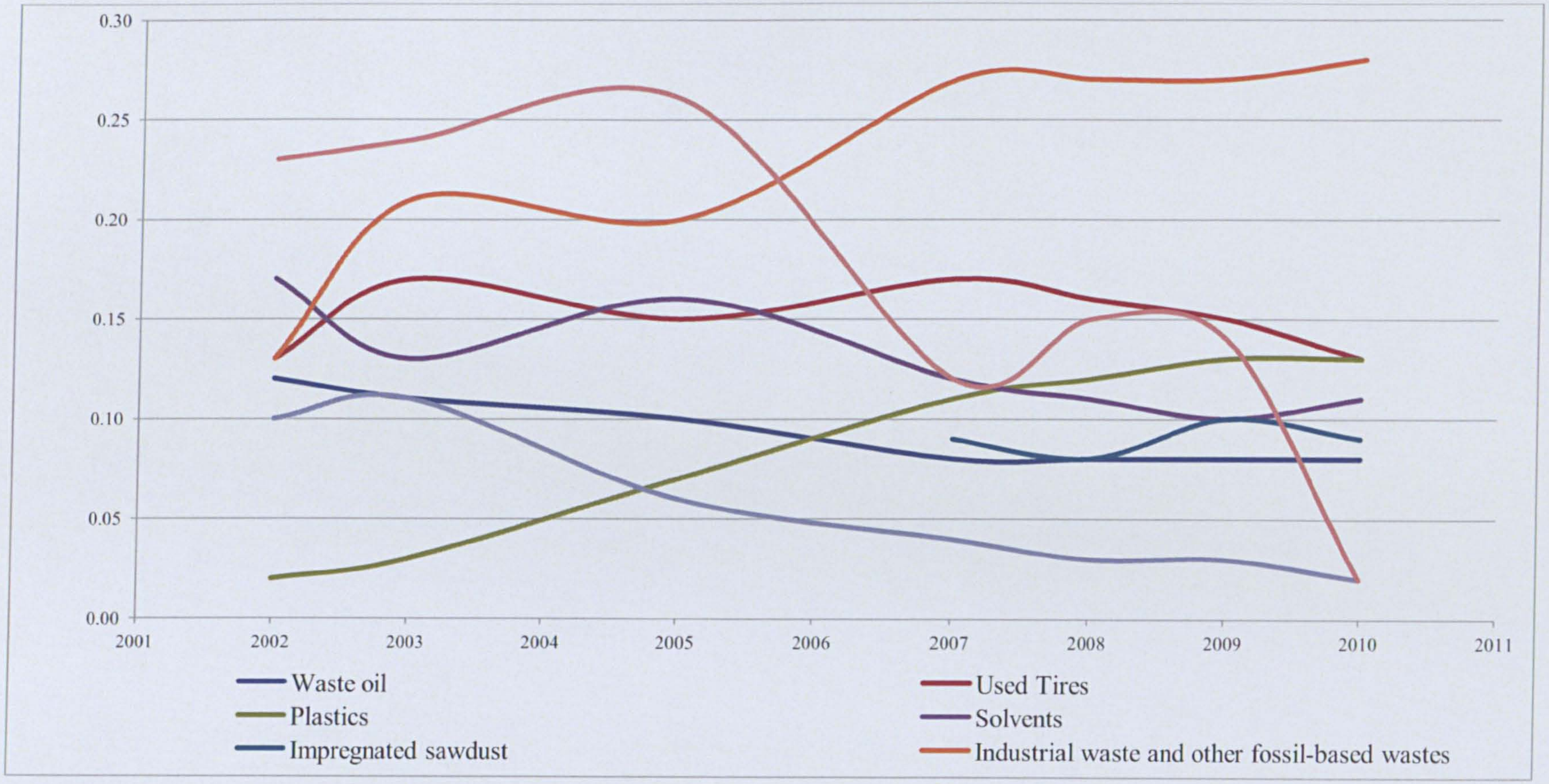
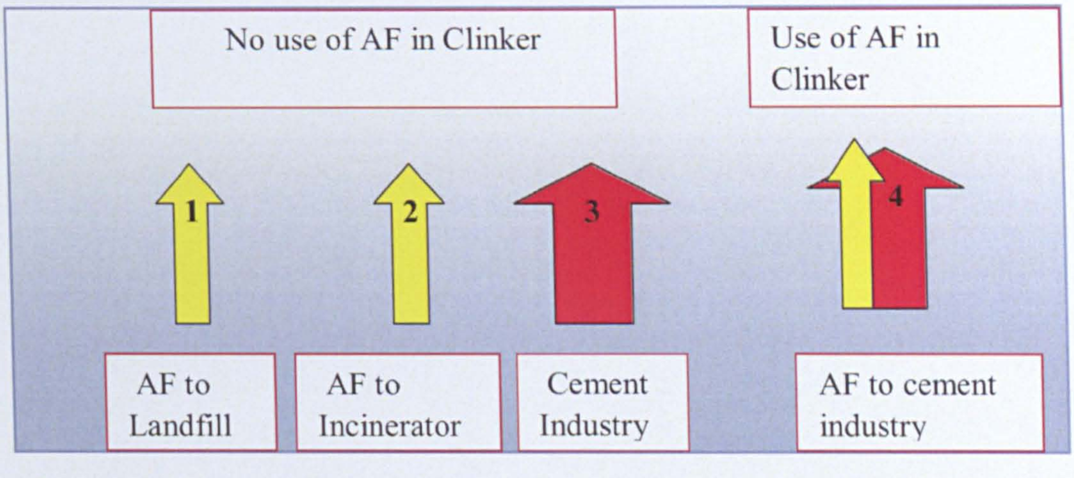


Figure 5.7 Improvement trends of waste utilization as alternative fuels at Holcim (2000, 2011), %.

5.3.2.1 Alternative fuels and thermal energy mix in cement operations at Holcim

Waste recovery at Holcim offered sufficient alternative fuels, conserved non-renewable resources and reduced CO_2 emissions by 10% in 2010 comparing with 5.8% in 1990 (Figure 5.8). However, wastes with a high heavy metal content may lead to increased air emissions of volatile heavy metals (such as mercury) and **AF usage means replacing the** conventional fuels which heat the cement kiln (mainly coal and petcock) with AF including natural gas and biomass fuel (Holcim SDR 2009). According to lab tests, (Figure 5.9) shows that these mixed fuels were 20 to 25% less carbon intensive than coal.

Figure **5.8** Improvement trends of total thermal energy efficiency from alternative fuels at Holcim between 1990 and 2010



1. Landfill gas (CO_2 and CH_4)
2. CO_2 from incineration
3. CO_2 from fossil fuels in CL
4. CO_2 from both systems if AF used in CL

Other options for CO_2 reduction:

- Reduction of Clinker Factor
- Process improvements(including waste heat utilization)

Figure 5.9 shows the CO_2 emissions output from ordinary Portland cement and the from cement materials utilized waste as fuel

However, three AF for conventional fossil fuels have been classified in Holcim cement operations, namely: biofuel, fuel blends, and synthetic fuels. These kinds of AF used at Holcim can be described as follows:

- Biofuel is fuel derived from biomass through various chemical processes; this fuel can be in the form of solids, liquids, or gases.
- Synthetic fuels can be produced using either renewable or non-renewable sources, starting with materials such as water, air, and carbon dioxide, or starting with fossil fuels.
- Fuel blends are very attractive blends of conventional and synthetic fuels or biofuel. A typical example is gasoline-ethanol blend, used by Holcim in many countries. Blends help to reduce CO_2 emissions.

5.3.3 Raw materials and ARM used in the cement making process at Holcim

Strict quality standards are set for cement at Holcim. The range of materials that can be used is limited, but includes both natural materials such as pozzolanas (volcanic ashes) and limestone, and by-products of industrial processes. Commonly used by-products include fly ash from coal-fired power generation, blast furnace slag from iron production and silica fume from silicon production. Use of mineral components in cement can offer improved properties of the final cement product, such as greater long-term strength, higher chemical resistance and lower hydration heat (Holcim SDR, 2002 and 2009). In addition to the key role of replacing part of the clinker with mineral additions, the practice results in the process requiring less thermal energy and fewer natural raw materials, and consequently producing fewer CO_2 emissions from the final cement product (Rosković and Bjegović 2005).

Because the emission factor of CO_2 released from the decarbonation process of natural raw materials fed into the kiln is 0.785 t CO_2/tonne CaO in clinker, replacing specific amounts of CaO with ARM leads to reduction of the emitted CO_2 (Marchal.G 2002).

By assessing the raw materials consumption at Holcim, it was found that the percentage of ARM used to replace the natural raw feed improved by 11%, coming from 98% in 1990 to 13% in 2010 (Figure 5.10).

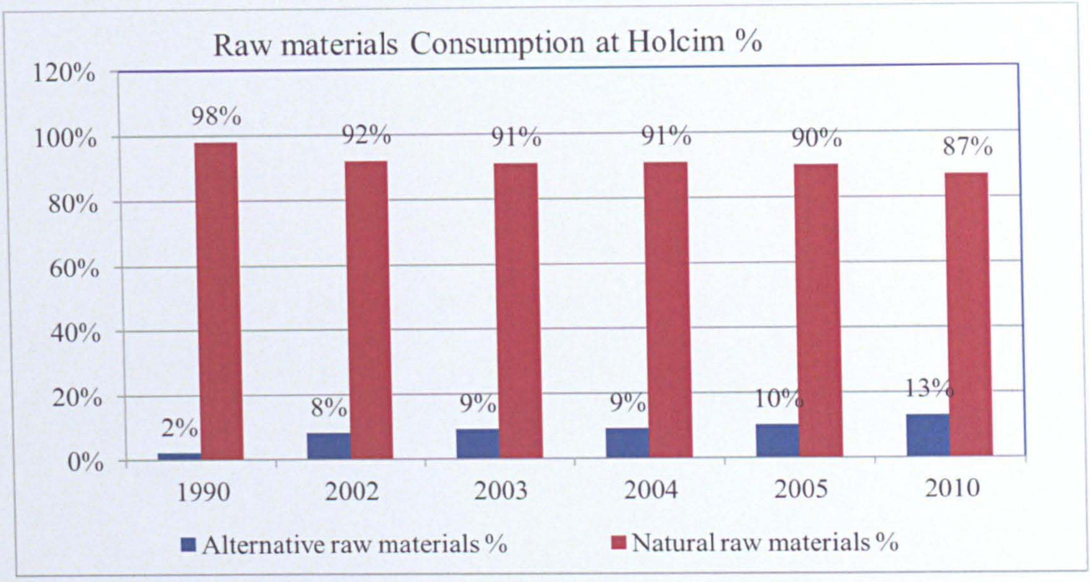


Figure 5.10 Improvements and changes in ARM usage at Holcim.

Furthermore, it was explained by Dr. Michel B. Monteil that the ARM are usually fed to the kiln system in the same way as the traditional raw meal supply. But ARM which have volatile components (organic or inorganic) at low temperature, such as hydrocarbons, must be fed into the high temperature zone, as they are restricted to introduction by the same method as normal meal, in order to avoid undesired stack emissions (Holcim-GIZ 2006). Pictures in Figure 5.11(a.left) and (b. right) were picked up in the test room and the laboratory.

Figures 5.11 (a. Left) and (b. right) Siggenthal cement operations laboratory.

Table 5.4 summarizes the alternative raw materials used in waste utilization at Holcim's cement operation and materials recovery from different types of waste (Holcim-GIZ 2006).

Table 5.4 Waste materials utilized in cement operations at Holcim to replace the natural raw materials

Compounds	Waste material	Industrial sources
Clay mineral/ Al_2O_3	• Coating residues • Aluminium recycling sludge	• Foundries • Aluminium industry
Limestone/$CaCO_3$	• Industrial lime • Lime sludge	• Neutralization process • Sewage treatment
Silicate/SiO_2	• Foundry sand • Contaminated soil	• Foundries • Soil remediation
Iron Oxide/Fe_2O_3	• Roasted pyrite • Mechanical sludge • Red sludge	
Si-AL-Ca-Fe	• Fly ashes • Crushed sand	• Incinerator • Foundries
Sulphur	• Gypsum from gas desulphurization • Chemical Gypsum	• Incineration • Neutralization process
Fluorine	• CaF_2 filter sludge	• Aluminium industry

5.3.4 Carbon dioxide emissions (1990–2010)

Various key approaches have had the effect of minimizing CO_2 emissions, including (Ali, Saidur et al. 2011):

- Lowering the clinker factor and introducing innovative cements including composite cements
- Improving thermal energy efficiency by using waste as alternative fuels and optimizing fuel composition
- Replacing conventional raw materials with non-hazardous ARM
- Improving the technology of the cement manufacturing process.

Correspondingly, additional specific indicators have been set by the research, in relation to WBCSD indicators for assessing carbon efficiency performance, for cement operations at Holcim from 1990 to 2010:

- Clinker factor: reducing the amount of clinker used to make one tonne of cement
- Specific heat consumption: increasing the thermal energy efficiency of the clinker making process
- Thermal substitution rate: increasing the proportion of energy from alternative fuels
- Raw material substitution rate: increasing the proportion of alternative raw materials used to replace traditional raw materials.

Inputs of the process: reducing the required amount of natural resources and CO_2 emissions by replacing conventional fossil fuels and raw materials with waste and industrial by-products.

Outputs of the process (Figure 5.12): reducing CO_2 emissions by improving operational procedures and technology.

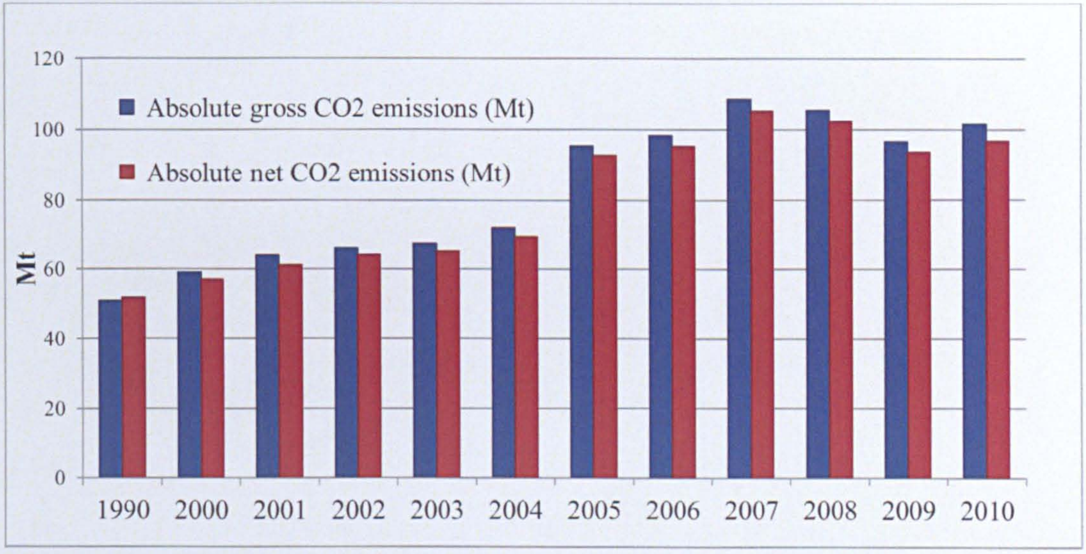


Figure 5.12 Total CO_2 emissions from cement operations at Holcim from 1990 to 2010.

The WBCSD set a CO_2 emissions reduction target of 20% reduction by 2010 for the organization's cement company members. As shown in (Figure 5.13)Holcim did not reach this target by 2010, as its gross CO_2 emissions per tonne of cement were down by 16.1% in comparison to 1990 CO_2 emissions, whilst the specific CO_2 emissions were down by 17%, according to the research assessment and data analysed for the period from 1990 to 2010. This result deviated from claims made in Holcim's 2009 SD report, which asserted that the specific CO_2 emissions from Holcim's cement operations were improved by 21% down from the 1990 level.

However, cement production increased by 100% in 2010, with an absolute net of 52% CO_2 emissions. Holcim has set a new ambitious target for 2015 to lower the CO_2 emissions by 25% per tonne of cement compared to 1990 levels (Holcim-Publications 2009).

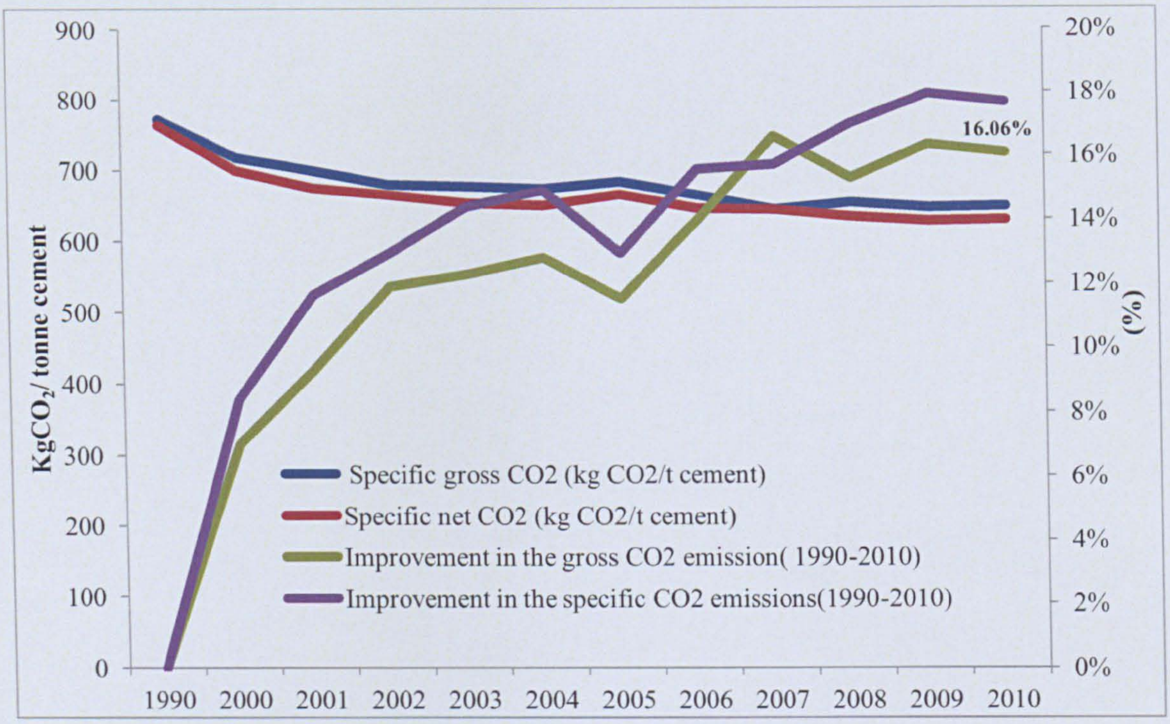


Figure 5.13 Improvement in carbon efficiency, gross and specific, at Holcim from 1990 to 2010.

5.3.4.1 Clinker factor (ratio of clinker/cement) and CO_2 emissions from clinker

A sizeable amount of CO_2 is emitted during clinker production, which is an energy-intensive process. Reducing the amount of clinker in cement can be considered one of the main drivers of CO_2 emissions reduction.

The clinker factor is the percentage of clinker in cement. Clinker can be replaced by other materials (known as secondary cementitious materials) to make different kinds of cement. Furthermore, lowering the clinker factor reduces the amount of fuel required per tonne of cement produced, and replacing the clinker with suitable waste materials reduces the volume of virgin raw materials required. But because of strict quality standards set for cement, the range of materials that can be used is limited. Suitable materials include fly ash from the power generation industry and blast furnace slag from iron production. Ordinary Portland cement is the most basic form of cement, with a maximum clinker factor of around 95% (added gypsum making up the remaining 5%). However, it was found that blending cement with the additives to replace clinker makes the most impressive contribution to the reduction of CO_2 emissions. In blended cement, the clinker/cement ratio is reduced by replacing part of the clinker with additives such as fly ash. An addition of about 10% fly ash to the cement would reduce annual CO_2 emissions substantially. Cement and concrete quality can also be improved by the addition of fly ash. Besides this, limestone, blast furnace slag, natural pozzolan, silica fume and volcanic ash may be used as additives. It was reported that granulated blast furnace slag is one of the widely used additives. These industry-based by-products are mixed with the ground clinker to give a blended cement product.

The data analysed showed that the global potential for CO_2 emission reductions through blended cement identifies it as one of the most effective ways to reduce CO_2 emissions. Figure 5.14 shows the improvement trends for the clinker factor at Holcim, which was 82.10 % in 1990, going down in 2010 to 71.5%.

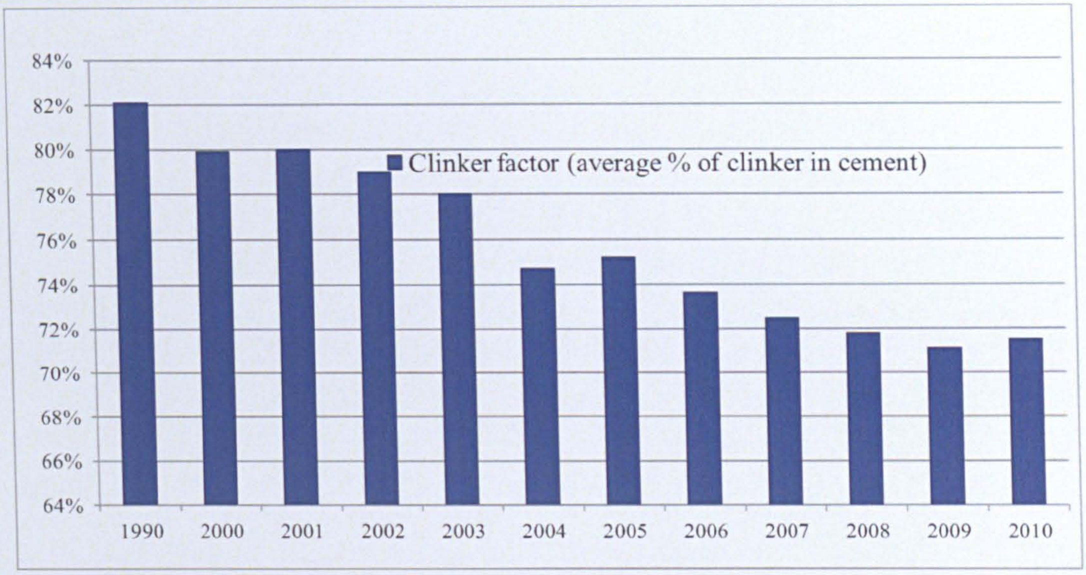


Figure 5.14 Development and reduction of clinker/cement ratio from 1990 to 2010.

Furthermore, replacing clinker with mineral components (such as waste and industrial by-products) is another significant driver of lower CO_2 emissions (Figure 5.15). This represents one of the best, technically proven approaches for reducing process emissions and is a key factor in the CO_2 reduction strategy (Hendrik G. van Oss 2003). The data analysis showed that the CO_2 released from clinker was reduced by bringing down the clinker factor. The reduction rate was 9.46% Kg CO_2/tonne clinker in 2010 compared to 1990 levels. As a result, the increase in AFR burnt and used in kilns in Holcim's cement operations reduced the environmental impacts of waste, safely disposed of hazardous wastes, minimized GHGs, minimized waste handling costs and saved money in the cement industry (Table 5.5).

Figure 5.15 Changes in mineral components used in cement produced at Holcim from 1990 to 2010.

5.3.4.2 Carbon dioxide emission following increase in rate of raw material Substitution

Further analysis has been conducted to calculate the CO_2 emissions resulting from the increase in the proportion of ARM (CO_2 from raw feed in Holcim's kiln). Since CO_2 emission is formed in the calcination process, which can be expressed by the following equation (C.A. Hendriks 2004):

$CaCO_3 \rightarrow CaO + CO_2$

1 Kg 0.56 Kg+ 0.44 Kg

The share of CaO in clinker amounts to 64–67%. The remainder consists of iron oxides and aluminium oxides. Therefore, the CO_2 emissions coming from clinker production account for about 0.5 Kg/Kg clinker. The specific process CO_2 emission for cement production depends on the clinker/cement ratio and raw materials used to make this clinker. The analysis showed in (Figure 5.16)that the average saving of CO_2 emissions in 2010 according to 1990 levels was 3.63%, since in 2010, CO_2 saving from ARM usage at Holcim reached 50.544 Kg CO_2 per tonne of cement in comparison to 1990 when CO_2 emissions saving was13.896 Kg CO_2/tonne cement.

Table 5.5 Natural and alternative raw materials used at Holcim through the manufacturing process up to the final cement product.

Material Category	origin	Examples
Raw materials (main)	• Natural • Alternative	• Limestone, marl limestone, coal ash • Industrial lime/sludge, fly ash
Corrective materials	• Natural • Alternative	• High grade limestone, quartz sand, bauxite, iron ore • Foundry sand, pyrite ash
Set Controllers	• Natural • Alternative	• Gypsum • Desulfurization gypsum
Mineral Compounds	• Natural • Alternative	• Pozzolana • Blast furnace slag, fly ash

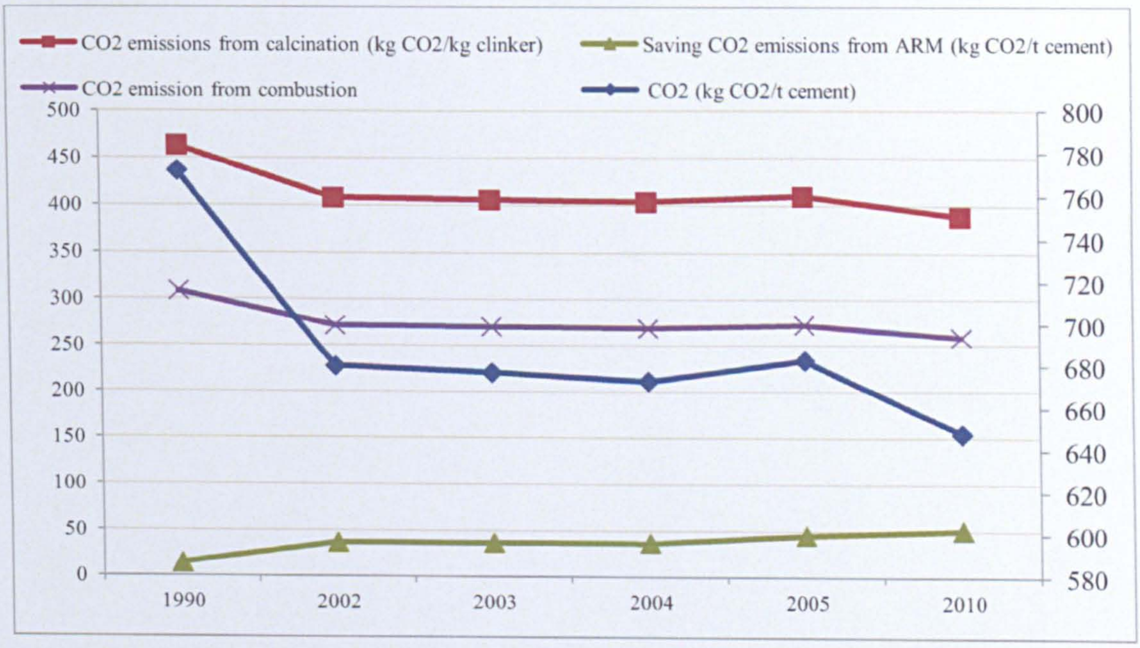


Figure 5.16 CO_2 emissions from cement, calcination process, and saving of CO_2 from ARM usage (Kg CO_2/tonne cement).

5.3.4.3 Increasing the thermal energy efficiency of the clinker-making process: specific heat consumption

The replacement of traditional fossil fuels with biomass residues and waste-derived fuels which recover energy from waste, replacement of natural raw materials with ARM in the calcination process, and optimization operations, resulted in improving the thermal energy efficiency of clinker (specific heat consumption) from 4544 MJ/tonne clinker in 1990 to 3555 MJ/tonne clinker in 2010. This significant improvement in efficiency of energy consumption led to a reduction in specific CO_2 emissions coming from energy by 6 % over the last two decades (1990 to 2010) (Figure 5.17).

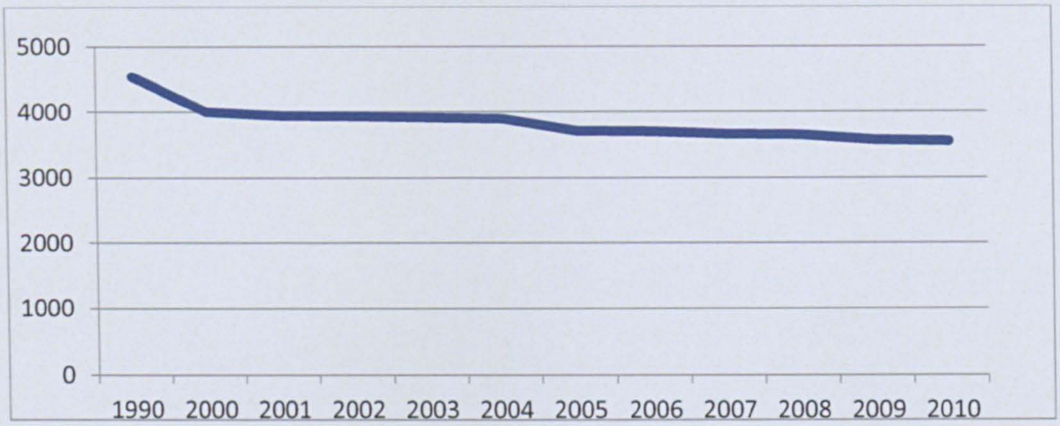


Figure 5.17 The increasing thermal energy efficiency (specific heat consumption MJ/ t clinker) in 2010, which is the total thermal energy consumed per tonne of clinker produced, compared to 1990 levels.

5.3.4.4 Increasing the proportion of energy from AF (thermal substitution rate)

The practice of replacing of fossil fuels by alternative, waste-derived fuels in Holcim's cement operations was sufficient to reduce fuel costs and CO_2 emissions, and to offer society a waste disposal service by dealing safely with wastes which are difficult to dispose of in any other way (Holcim-publications 2003) (Holcim-Publications 2009).

In 2001, Holcim's thermal substitution rate was more than double that of 1990. This is equivalent to replacing 1.3 million tonnes of coal per year, by recovering 1.8 million tonnes of waste. In Western Europe and North America, the substitution rates quadrupled in a decade to nearly 29% and 17% respectively in 2001. Latin America increased its rate to 9% in 2001, while in Asia and Africa fuel substitution is in the first stage of development. In 2005, the thermal substitution rate was 12.8% (Holcim-Publications 2005). This is the rate at which Holcim substituted non-traditional fuels for standard fossil fuels and is equivalent to saving 1.7 million tonnes of coal and using 2.5 million tonnes of waste.

In 2010, Holcim's thermal energy consumption performance was improved to reach 3555 MJ per tonne of clinker, lower than the 1990 level of 4500 MJ per tonne of clinker. Simultaneously, the replacement of traditional fossil fuels with biomass residues and waste-derived fuels, thus recovering energy from waste, increased by 8.4%

in 2010 compared to 1990, as the AF rate was 12.1% in 2010 and 3.7% in 1990 (Figure 5.18).

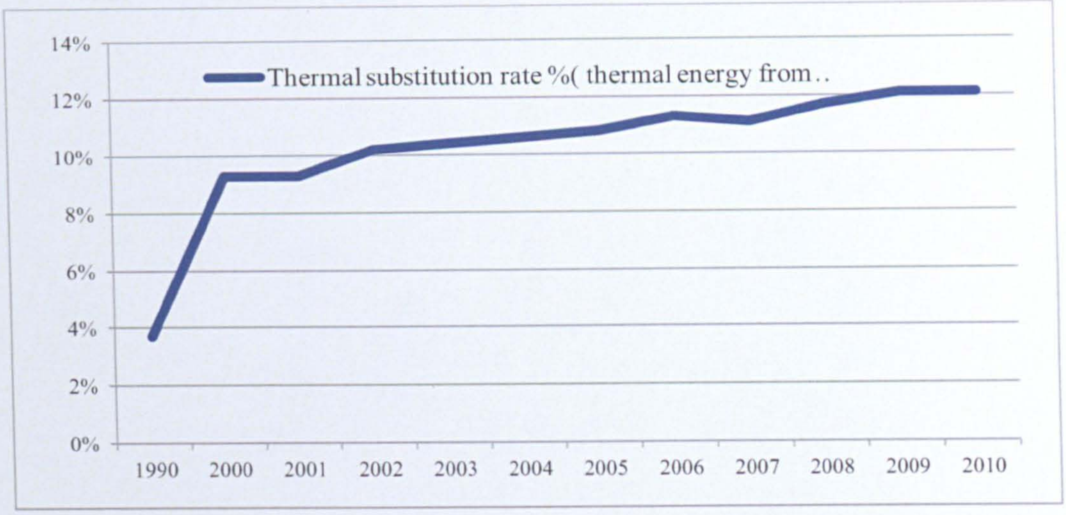


Figure 5. 18 Improvement trends in thermal energy efficiency from alternative fuels usage from 1990 to 2010.

5.4 Discussion and conclusion

Based on 2006 GNR data, the global average clinker ratio was 78%, equivalent to more than 500 million tonnes of clinker-substituting materials used for 2400 million tonnes of cement produced. At Holcim, the normal volumes of clinker for Portland cement varied between 87% and 95% for ordinary Portland cement. Usually, the more mineral components are added, the better is the quality of cement. In addition, this practice reduces the volumes of clinker used, and also the process-, fuel- and power-related CO_2 emissions associated with the process of clinker production.

Although technically, cement kilns at Holcim cement could use up to 100% alternative fuels, there are some practical limitations. The physical and chemical properties of most AF differ significantly from those of conventional fuels, while some (such as meat and bone meal) can be used easily by cement operations (Holcim-GIZ-nIw 2008).These are related to, for example, low calorific value, high moisture content, or high concentration of chlorine or other trace substances such as volatile metals (e.g. mercury) which must be managed carefully, with adequate removal of cement kiln dust from the system. This entails pre-treatment (pre-processing) which is needed to ensure more uniform composition and optimum combustion, followed by the co-processing of these materials as AFR (WBCSD&IEA 2009). In this regard, and to assess the environmental impact of cement operations at Holcim, indicators have been identified which help to track progress against the impact. These indicators cover implementation of best available technology, alternative fuels and alternative raw materials use, and clinker substitution at Holcim cement operations worldwide, taking into account that the implementation of CO_2 intensity reduction applications is unpredictable and the technology advances at varying speeds.

These Environmental Performance Indicators include the following (Figure 5.19):

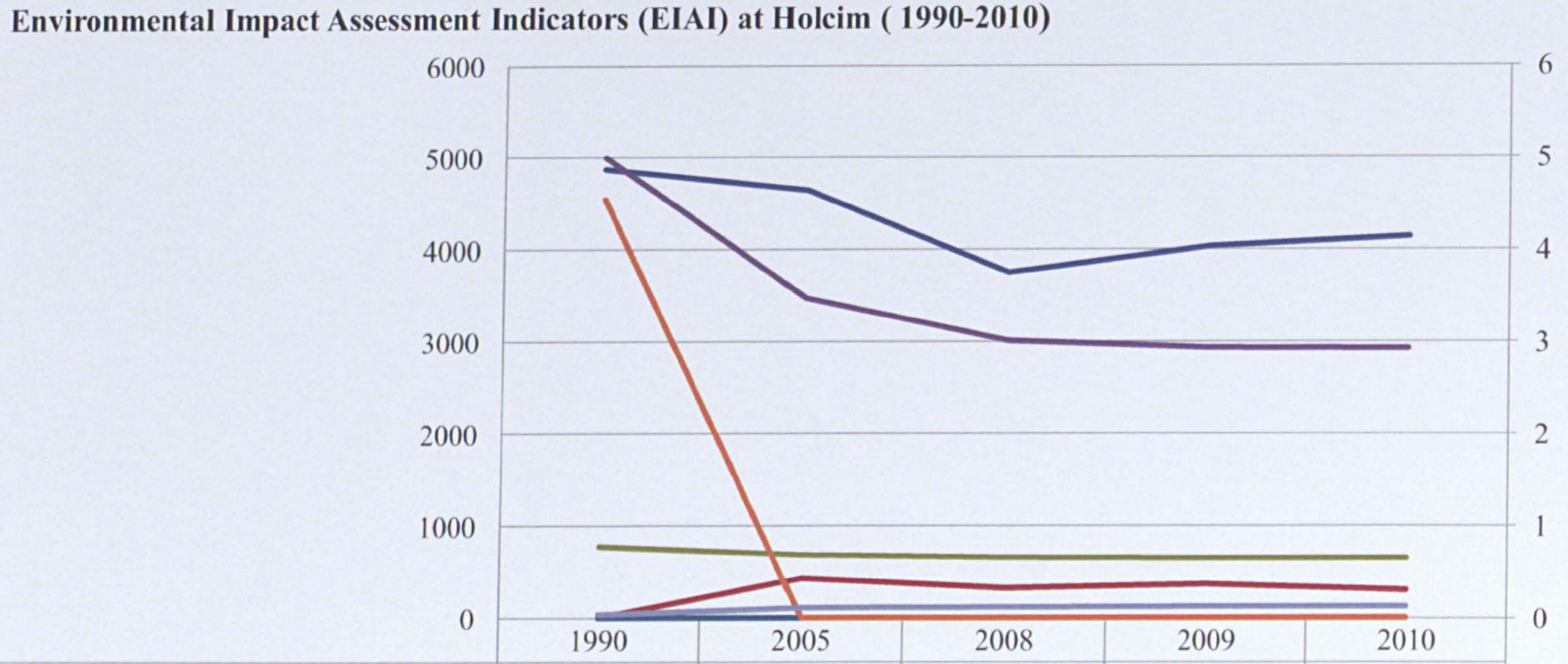
- Total specific net CO_2 (Kg/tonne cement)
- Total specific gross CO_2 (Kg/tonne cement)
- Total heat consumption (MJ/tonne cement
- Specific electricity consumption (10MJ/tonne cement)
- Total usage from alternative fossil fuels and biomass consumption
- Alternative raw materials
- Clinker factor, water consumption, and finally waste utilization (waste-related fuels and related raw materials).

Table 5.6 CO_2 emission saving and natural resource conservation (1990–2010)

CO_2 saving from using ARM Kg/Kg cement	-2.64%
CO_2 saving from using AF	-6.42%
CO_2 saving from clinker reduction (calcination)	-9.64%
Total CO_2 savings Kg CO_2/tonne cement	-16.06%

A key contribution towards reduction of CO_2 emissions and fossil fuel dependency has been provided by using alternative fuels and alternative materials throughout the cement manufacturing process at Holcim. These substitutions have reduced CO_2 emissions across Holcim plants, reduced the quarrying need and the environmental impacts of such activities, and maintained the quality of the final product.

Table 5.6 shows the CO_2 emission saving and reduction rates within each of the main steps in the process of cement making (raw material calcination, clinker burning and fuels usage).



	1990	2005	2008	2009	2010
— Employer (person/t/y)	4866	4643	3748	4030.9	4136
— Water consumption (l/t/y)	0	430	320	360	300
— CO2 (kg emissions /t cement)	772	683	655	646	648
— clinker factor % /t cement	84.00%	75.00%	71.80%	71.10%	71.50%
— Thermal energy effeciency(Mj/t clinker)	4544	3.821	3.661	3.605	3.555
— fuel consumption cement(Mj/t)	4.998	3.473	3.007	2.932	2.925
— thermal energy from alternative fuels%	3.70%	10.60%	11.70%	12.10%	12.10%

Figure 5.19 Clarification of the identified indicators and assessment of environmental impacts progress for specific year

Chapter 6

Case study for Taiheiyo Cement Corporation Worldwide

6.1 Introduction

Various activities were prompted and developed by Taiheiyo Cement Corporation to increase energy efficiency, reduce CO_2 emissions, and conserve natural resources These activities will be reviewed and analysed in this chapter. Since comprehensive recycling system has been established by Taiheiyo Cement Corporation to provide AFR derived from industrial wastes and by-products. Taiheiyo has developed three municipal waste recycling technologies including Eco-cement (will be mentioned later in this chapter), Fly Ash Washing System, and the AK System (SDR 2010). Urban waste utilization offers a new method of cement production and energy conservation, a new valuable product for cement market, and new recycling technologies which can save valuable fossil fuels for future generations and reduce CO_2 emissions associated with fuels combustion and raw materials calcinations. The present critical case study, which relies on data and observed practices of Taiheiyo Corporation, was undertaken to analyse technologies of urban waste utilization such as incineration ash and sewage sludge.

The experimental results of a study by Wu, K., Shi, H. and Guo, X. in 2011 confirmed that waste utilization and replacement of the raw feed of cement by MSW could be applied to 30%, with firing of the raw mixes carried out at 1250°C for 2 hours. The research makes clear that increasing the usage of wastes to replace either raw materials or natural fuels in cement production can reduce CO_2 emissions by 0.1 to 0.5 Kg/Kg cement.

In this regard, according to research conducted by Michael Taylor and Cecilia Tam in 2006 for the IEA, Japan which is one of the most energy-efficient countries, and an efficient clinker producer. A significant reduction in the Japanese cement industry's energy requirement to produce one tonne of clinker, when compared with that of other countries, has been achieved. Figure 6.1 confirms that Japan is the most energy-efficient clinker producing country, as the energy requirement of the Japanese cement industry, including AF, is below that of other nations (Michael Tylor 2006).

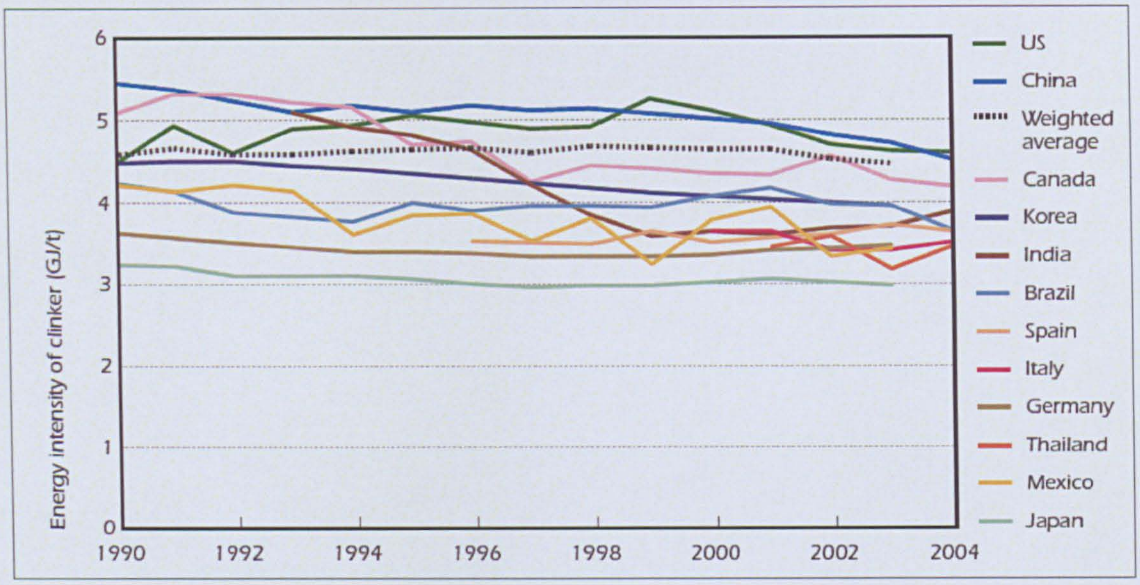


Figure 6.1 Energy requirements per tonne of clinker by country including alternative fuels (Michael Taylor 2006).

6.2 Energy consumption by the cement industry in Japan

Japan has 18 cement companies and 32 cement plants, with a clinker production capacity that reached 63 million tonnes in April 2009 (JCA 2009). According to the GNR project (WBCSD), the absolute gross CO_2 emission produced by the Japanese cement industry was 72 Mt in 2007, fuel consumption was equivalent to 108 Kg/tonne cement, and specific power consumption was 103 kWh/tonne cement in 2007 (JCA). Figure 6.2 shows Japanese CO_2 emission in comparison with that of other countries' cement industries. Similarly, Figures 6.2, 6.3, and 6.4 show the relevant energy and waste utilized by the Japanese cement industry.

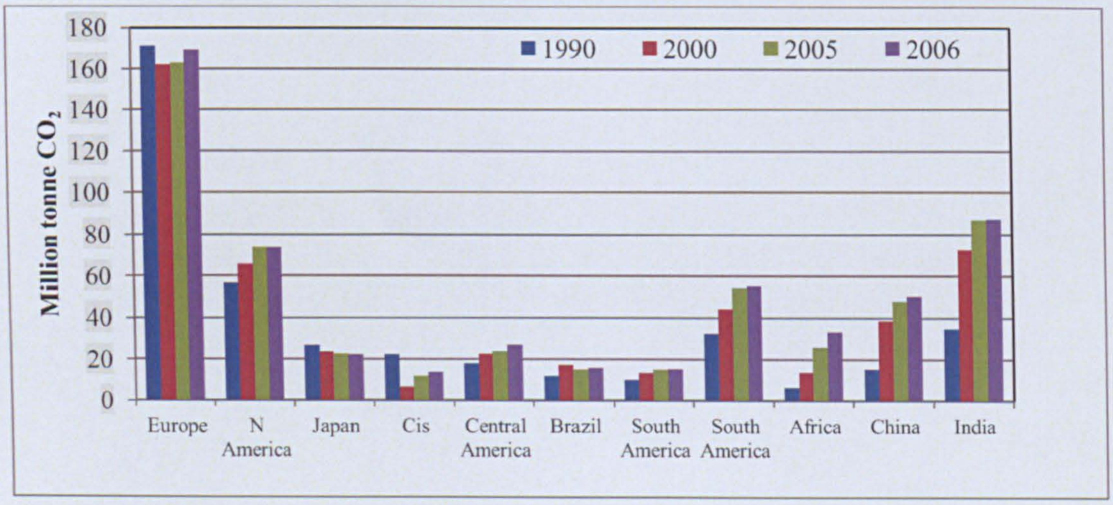


Figure 6.2 Japanese CO2 emission compared to the World (Mt) (WBCSD-GNR 2006).

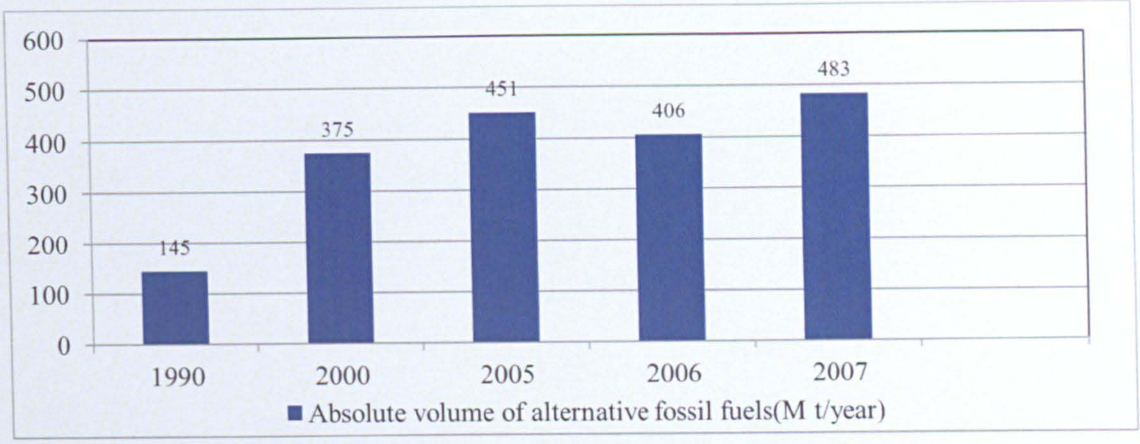


Figure 6.3 Absolute volumes of alternative fossil fuels In Japan (Mt/year)

However, a shortage of waste disposal sites, primarily in Japan with its mountainous features, high population density and increase in pollutants emission, makes waste reduction an urgent need. According to the Japan Environmental Agency, the total waste produced per year is equivalent to 450 Mt (JEA). This waste is classified mainly as industrial waste (400 Mt) from the processing of natural resources into industrial products, and the rest is municipal waste. Over 60% of this waste is either incinerated or dumped in landfills (JEA). However, as shown in (Table 6.1) municipal solid waste (MSW) Incineration contributes to volume reduction as 6.1 Mt of incineration ash is land filled annually (which is still problem for local municipalities)

Table 6.1 Treatment of municipal waste in Japan (IEA- Cement Energy Efficiency workshop 2006) .

Population of Japan=120 million Total Municipal Solid Waste (MSW) raisings 50 million tonnes/y	Incineration 38 Mt	Total Landfill 13.6 Mt/y
	Recycling 4.9 million	Ash= 6.1 Mt
	Others 1.2 millions	Others =1.8 Mt
	Direct landfill 5.7 Mt	Direct landfill= 5.7 Mt

According to the JCA , the amount of waste materials and by-products utilized in the production of 1 tonne of cement by the Japanese cement industry reached an average of 448 Kg/tonne cement in 2008 (Japan.Cement.Association 2008). Japan has made impressive efforts to develop energy efficiency technologies, and the difficulty of securing new sites for waste dumping will be further overcome by the introduction of an industrial ecology approach.

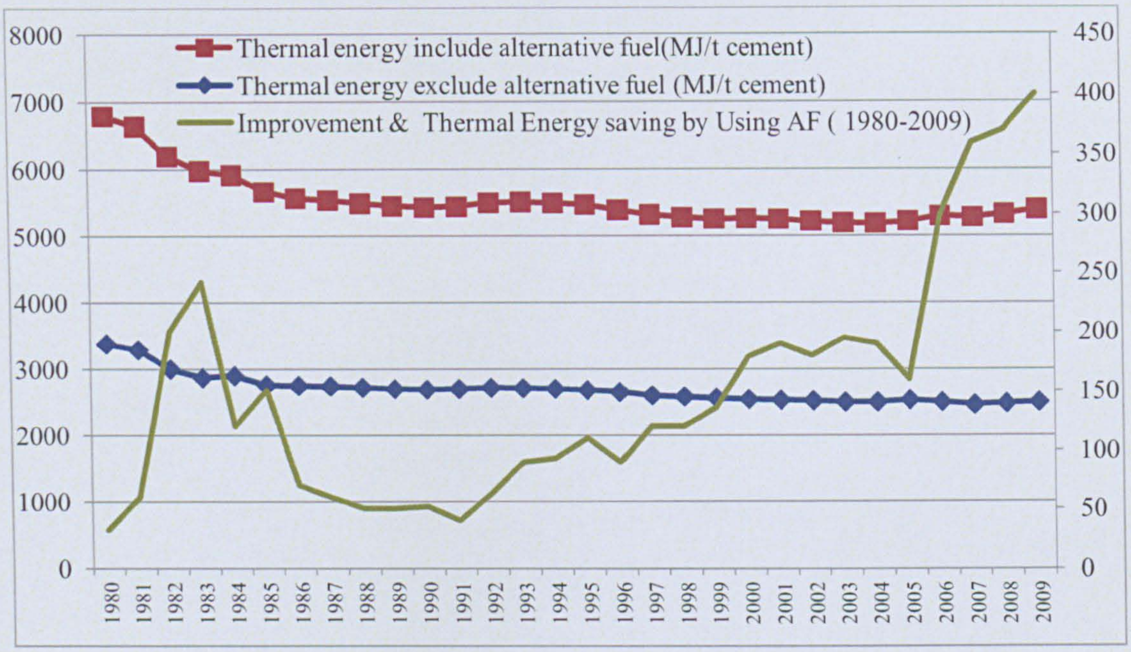


Figure 6.4 Improvement of Thermal Energy Consumption by the Japanese cement industry (MJ/ tonne cement) 1980–2009 (JCA).

AF usage in Japan had increased by 11.5% in 2009 compared to 1980 as shown in (Table 6.2); this increment represents thermal energy equal to 368 MJ/tonne cement.

Table 6.2 Saving in Energy consumed by Japanese cement Industry from 1980 to 2009.

Saving in Energy consumed by Japanese cement Industry	Thermal energy saving 1980–2009 MJ/tonne cement	Saving Ratio in energy consumed
Exclude AF	878	26%
Include AF	510	14.5%
Total saving of energy consumed	368	11.5%

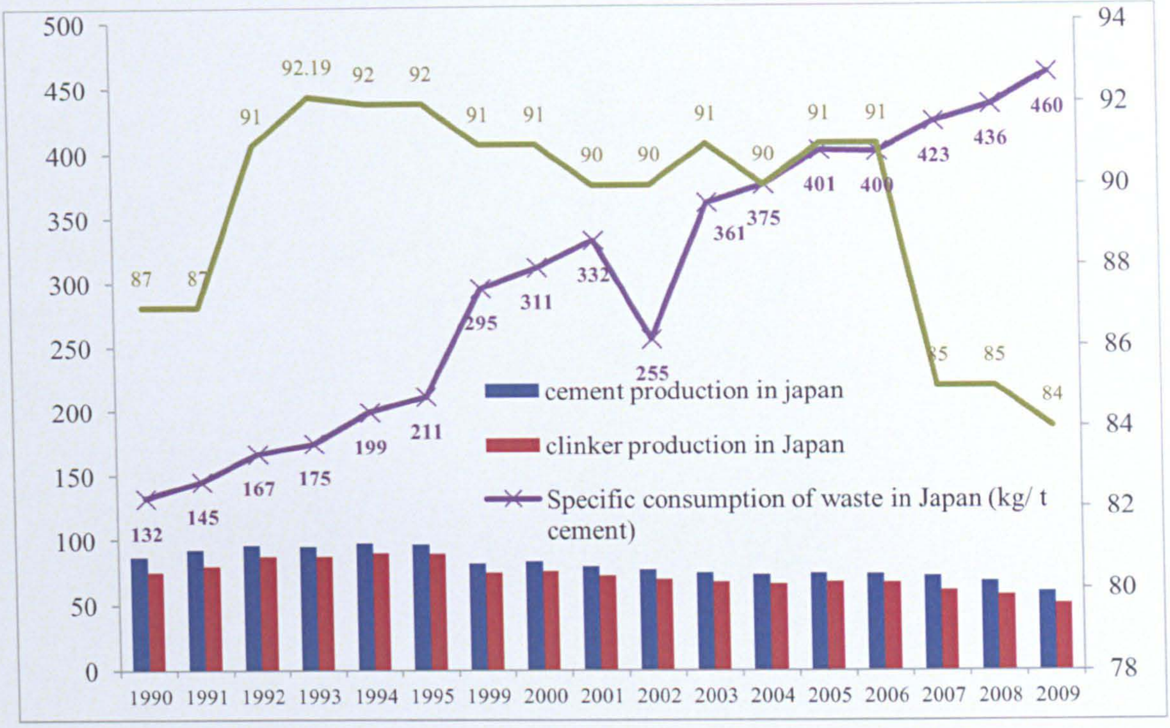


Figure 6.5 Trends in cement production (Mt), clinker production (Mt), clinker factor (%), and the improvement of waste consumption (Kg/ tonne cement) in Japan (JCA 2010).

According to the JCA, attested by Taylor, Tam and Gielen at an IEA–WBCSD workshop in September 2006 (Michael Tylor 2006), each tonne of clinker produced by Japanese rotary kilns required about 100 kWh for raw materials grinding and cement grinding. Consequently Japan has been classified by the WBCSD as one of the most efficient countries, exhibiting one of the best practices, taking into account that the energy efficiency of grinding is only 5% to 10% of the total thermal energy consumption and varies with each plant in the same country or even the same company.

In addition, Japan was considered the most energy-efficient country by virtue of using 100% dry process technology to produce Portland cement clinker (Michael Taylor 2006) (WBCSD&IEA 2009). This helps to reduce the energy required for burning clinker in the kiln, establishing Japan as the most energy-efficient country per tonne of clinker, with superior performance for the dry rotary kiln, over the last two decades. Thermal consumption for Japan's cement operations ranged between 3.3 GJ/tonne clinker in 1990 to 2.800 GJ/tonne of clinker in 2009, including the alternative fuels (Japan.Cement.Association 2010).

In terms of AFR usage as shown in (Figure 6.6), around 210 tonne of scrapped tyres were burnt by the cement sector in 2008, 480 Kilo tonne of waste oil, 390 Kilo tonne of wood chips and 340 Kilo tonne of waste plastic (Japan.Cement.Association 2008). This was equivalent to 948 GJ per tonne of cement burned from alternative sources, assuming 426 GJ/tonne derived from waste oil, 1.66 GJ/tonne from wood chips and 356 GJ/tonne from waste plastic.

Although alternative materials are used widely in Japan, Taylor's estimation of clinker-to- cement ratio in 2006 in different countries and regions showed that Japan had the biggest ratio from 1980 to 2005, the clinker factor reaching 84% in 2010. Besides the implications for CO_2 emissions reduction, since the CO_2 emissions coming from clinker burning account for 60% of the total CO_2 released (Ernst Worrell 2001), this finding emphasizes the importance of using significant amounts of substitute materials such as pozzolanic, fly ash, and blast furnace slag: each 2 million tonne of blast furnace slag lowering the clinker ratio by 2 percentage points (Michael Tylor 2006).

Therefore, effective policies for reducing CO_2 emissions must not only focus on the efficiency of consumed energy or fuel substitution, but also address the emissions problem throughout the entire cement manufacturing process.

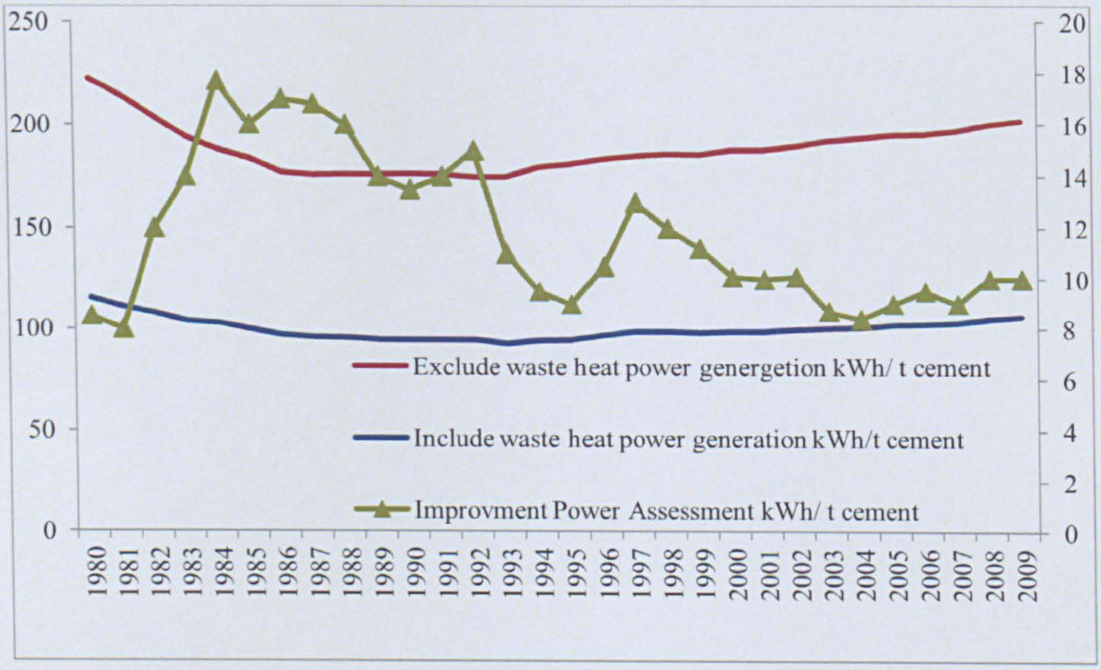


Figure 6.6 Improvement tendency of specific power consumption by the Japanese cement industry (kWh/tonne cement) in 2009 compared to 1980 levels.

6.3 Recycled municipal waste as alternative fuels and raw materials for cement production

The lifetime of Japan's landfills is shrinking, and it has become very difficult to find new landfill sites. This situation has made it necessary to treat these wastes as a key issue for the Japanese government (Wu, Shi et al. 2011). In this regard, Japan in general and the Taiheiyo Cement Corporation in particular have become world leaders by launching three different systems (Eco-cement system, Fly ash washing system, and AK system) for recycling municipal waste into mineral resources, and by struggling to resolve environmental issues (Japan Cement Association 2010).

Waste and by-products have been recycled as resources for cement at Taiheiyo. This practice promotes the extension of landfills' lifetime, prevents the depletion of natural mineral resources, and reduces GHG emissions and air pollution. In 2009, 263.5 Kg of waste and by-products were recycled as resources for Japanese cement works for every tonne of cement manufactured.

However, Figure 6.7 shows that in fiscal 2009, due to the decline in industrial activities, both the total volume and the rate of consumption fell from the fiscal years 2006 and 2007 (Japan Cement Association 2010).

Furthermore, whilst there are many kinds of hazardous wastes that are suitable to use as AF or to be incorporated in the process as raw material, there exists a negative list of wastes that it is forbidden to feed into cement kilns. This list is always part of the transaction permit that every Japanese cement kiln must obtain from the authorities in order to burn hazardous wastes. Such wastes are defined by William F Martin in 2000 his as "any substance which exceeds a threshold level of one or more of the following inherent hazardous properties: an explosive nature, flammability, an oxidising nature, toxicity, corrosiveness, ecotoxicity with or without bioaccumulation, evolving substances with one or more of the above properties on release into the environment" (William F.Martin 2000).

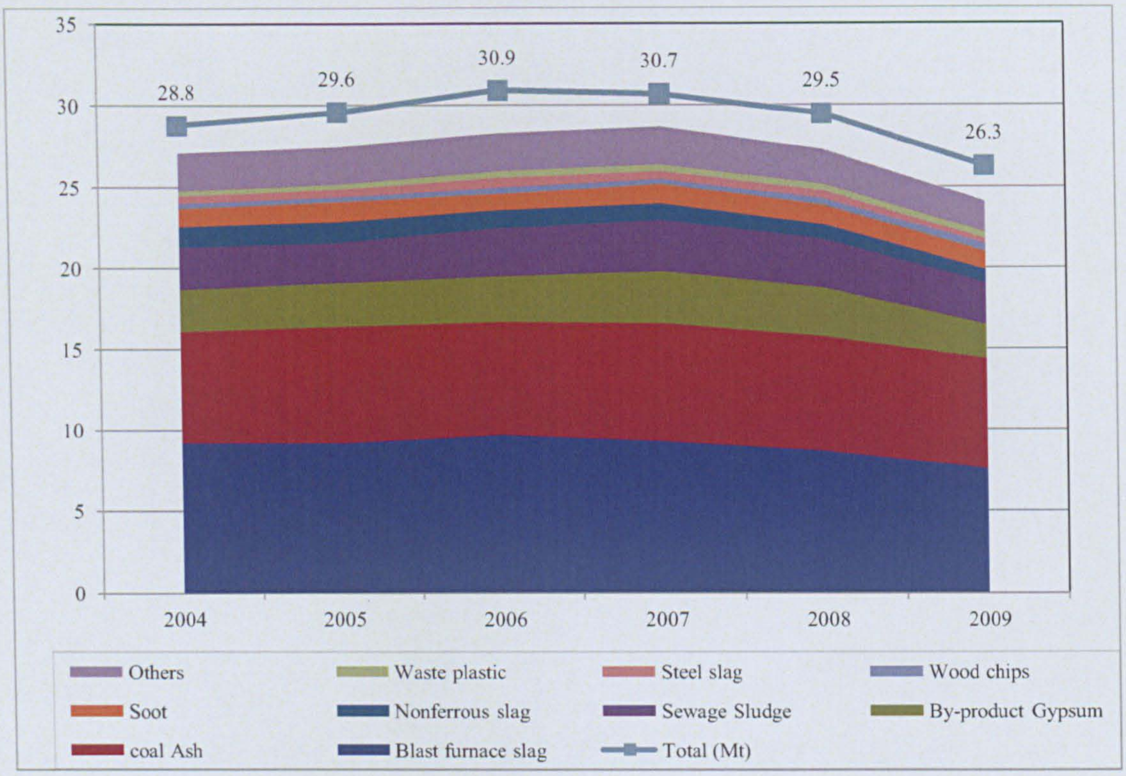


Figure 6.7 Types and quantities (Mt) of waste materials used in the Japanese cement industry (Japan Cement Association 2010).

The benefits to the environment arising from the cement industry's attention to hazardous waste management are basically two. The first one is related to the many types and large amounts of hazardous waste that are fed into cement kilns, providing alternative fuel or raw materials for cement production. These practices are very safe for the environment, because of the high temperature and long-time of residence that are necessarily applied in a cement kiln, the final purpose of which is the production of cement rather than waste management. As a result, the two earlier-mentioned parameters are always steady, and guarantee a very low environmental risk. The second benefit is the great saving in conventional fuel when it is replaced by hazardous wastes.

6.4 Taiheiyo Cement Corporation

Taiheiyo Cement Corporation is one of the leading Japanese cement companies. Taiheiyo Corporation resulted from a union between Chichibu Onoda Cement Co. and Nihon Cement Co. in 1998. The company has utilized AFR derived from industrial wastes and by-products for many years. Furthermore, a comprehensive recycling system for industrial wastes and by-products has been created by Taiheiyo in 2000, which includes new waste recycling technologies such as Eco-cement, the Ash washing process, the AK system and the Ash centre system. The company has also positioned its zero emission operations as a core business activity (Taiheiyo.Cement.Corporation 2012). To promote these activities, it established the Zero Emissions Promotion Department in April 2000, and defined it, in line with the definition provided by the United Nations Environment Program (UNEP), as "Recycling all waste generated from business activities, reducing incineration and landfill of waste to zero, and bringing its environmental impact from air quality and water quality as close to zero as possible".

The rate of limestone consumption fell from fiscal 2008 and 2007 (390.1 Kg/ tonne cement and 389.6 Kg/tonne cement), due to a decline in industrial activity. However, it was still higher than the rate of the used waste in 2000, which was 267.3 Kg/tonne cement. Two types of waste used effectively as alternative raw materials are coal ash from thermal power plants, and soil and sewage sludge from construction, which have been used increasingly.

The total cement production of Taiheiyo in 2008 was 20 Mt with waste usage of 365.2 Kg per tonne of cement, which is 2% less than the total cement production in 1999, and more than 1.5% of waste material usage which was 259 Kg/tonne cement. Table 6.3 below shows the effective utilization of various types of waste and by-products as recycled materials resources at each stage of the cement manufacturing process(Taiheiyo.Cement.company 2008). In the fiscal year of 2009 (which is ending 31 March 2010), 387.5 Kg of waste and by-products had been recycled per tonne of cement at Taiheiyo. Table 6.3 shows different types and amounts of wastes materials used for cement production in Teiheiyo.

Table 6.3 Consumption amounts and rates of various wastes materials and by-products at Taiheiyo Cement Corporation (www.taiheiyo.com) .		**Total Consumption (tonne)**			**Rate of Consumption (Kg/tonne-cement)**		
		FY03/06	**FY03/07**	**FY03/08**	**FY03/06**	**FY03/07**	**FY03/08**
Industrial Waste and By-Products	Waste Oil	70,072	66,307	66,157	3.3	3.2	3.4
	Recycled Oil	70,186	79,287	81,259	3.3	3.8	4.2
	Used Clay	3,184	3,490	2,696	0.2	0.2	0.1
	Used Tyres*	65,461	51,507	49,501	3.1	2.5	2.6
	Blast furnace Slag	1,313,685	1,258,346	1,233,789	62.6	60.9	64.1
	Converter Slag	65,941	108,327	74,245	3.1	5.2	3.9
	Non-Ferrous Slag	379,287	345,052	331,820	18.1	16.7	17.3
	Molding Sand	200,921	236,779	247,449	9.6	11.5	12.9
	Unburned Ash, Dust	407,840	324,031	335,902	19.4	15.7	17.5
	Coal Ash (including JIS fly ash)	2,217,391	2,114,838	2,131,209	105.7	102.4	110.8
	Sludge	385,143	444,827	558,601	18.4	21.5	29.0
	By-Product Gypsum	706,377	709,051	646,284	33.7	34.3	33.6
	Construction Waste	25,648	132,522	103,615	1.2	6.4	5.4
	Wood Chips	125,727	125,374	95,651	6.0	6.1	5.0
	Construction Soil	747,271	909,639	761,864	35.6	44.0	39.6
	Waste Plastic	81,985	87,257	88,574	3.9	4.2	4.6
	Other (raw material-related)	120,298	108,757	94,125	5.7	5.3	4.9
	Other (fuel-related)	69,317	66,120	64,231	3.3	3.2	3.3
	Subtotal	7,055,734	7,171,511	6,966,973	336.2	347.2	362.2
Household Waste	Municipal Incinerator Ash	58,569	60,842	69,935	2.8	2.9	3.6
	Water Treatment Plant Sewage Sludge and Ash	246,988	318,119	351,295	11.8	15.4	18.3
	RDF (refuse derived fuel)	6,731	5,964	4,282	0.3	0.3	0.2
	Other Municipal Waste	15,507	15,996	15,580	0.7	0.8	0.8
	Subtotal	327,796	400,921	441,092	15.6	19.4	22.9
Total Waste		7,383,530	7,572,432	7,408,065	351.8	366.6	385.2
	Raw Material-Related	6,894,050	7,090,617	6,958,410	328.5	343.3	361.8
	Fuel-Relented	489,479	481,815	449,655	23.3	23.3	23.4

6.5 Municipal waste recycling systems for cement production at Taiheiyo cement operations

Three municipal waste recycling technologies have been developed by the Taiheiyo Corporation to prompt the future sustainability of cement operations. These technologies are called Monoester Recycling Systems and include: Eco-cement, Fly ash washing system, and the AK System. The utilization of MSW in Taiheiyo's cement production process has been motivated by different factors including (Wu, Shi et al. 2011):

- Poor landfill capacity.
- New capacity planning difficulties and cost.
- Opportunity to create a Resource Recycling Society.
- MSW incineration ash contains the essential chemical components for cement as shown in (Table 6.4)
- The incineration ash coming from MSW incineration has the same compound as Portland cement (Silicon Dioxide SiO_2, Calcium Oxide CaO, and Aluminium Oxide Al_2O_3).

Table 6.4 Chemical Compounds (SDR of Taiheiyo 2008)

	CaO (%)	SiO_2 (%)	AL_2O_3 (%)	Fe_2O_3 (%)	SO_3 (%)
Cement	62-65	20-25	3-5	3-4	2-3
Incineration Ash	12-31	23-46	13-29	4-7	1-4

During the process of incineration the municipal waste retained in the municipal incinerating plant is the residue from the process of incineration. Two kinds of residue are generated:

- Bottom Ash: the residue generated by the incineration process.
- Fly Ash: the dust extracted from the exhausted gas by a bag filter.

6.5.1 Fly ash washing system

Municipal waste ash consists of:

1. Fly ash with high levels of chlorine which must be removed by a chlorine dissolving tank
2. Bottom ash with lumps which need to be removed (see Figures 6.8 and 6.9).

The Fly Ash Washing System recycles both these kinds of ashes for use in ordinary Portland cement. By that system the incinerated ash can be transported to a regular Portland cement plant to be utilized as an alternative raw material in the production of ordinary Portland cement. At the municipal incineration plant, fly ash generated during the waste burning process is collected by a bag filter and transported by tank lorry to fly ash receiving tanks (Figure 6.8) and (Figure 6.9). 20% of this fly ash consists of chlorine (10%–20%), which affects the quality of the cement. However, this compound is removed by the fly ash washing facility (in the De-chlorination washing process). Here, the fly ash is placed into a tank to be washed by water heated to 50°C and stirred for one hour. After the chlorine compound dissolves, the resulting solution can pass through the continuous belt filter for filtration and De-hydration, containing: 97% De-chlorination Rate (filter cake) and filtrate.

As shown in (Figure 6.10) regarding the process of fly ash washing system, the filter cake of fly ash is then used as a clay substitute in the rotary kiln. The small amount of Dioxin contained in the fly ash decomposes at a temperature of 1450°C, following which, in the CO_2 reaction tower, kiln exhaust gases are injected into the filtrate, carbon dioxide contained in the exhaust gas decreases the Ph of the filtrate, and heavy metals in the filtrate settle in the sedimentation tank ready for removal. The filtrates pass through a Chemical Reaction Tank and Filtrating Tower for further sedimentation and extraction of heavy metals. The sediment is filled together with the filtrate cake in the rotary kiln for the final detoxification after removal of the heavy metals. After being cleaned in the existing cleaning system, the purified filtrate is then discharged into the sewage system. In this way, the municipal waste incineration ash is utilized as alternative raw material in Portland cement production without any detriment to its quality. The Fly Ash Washing System is at full service capacity at the Taiheiyo cement plant in Kumagaya.

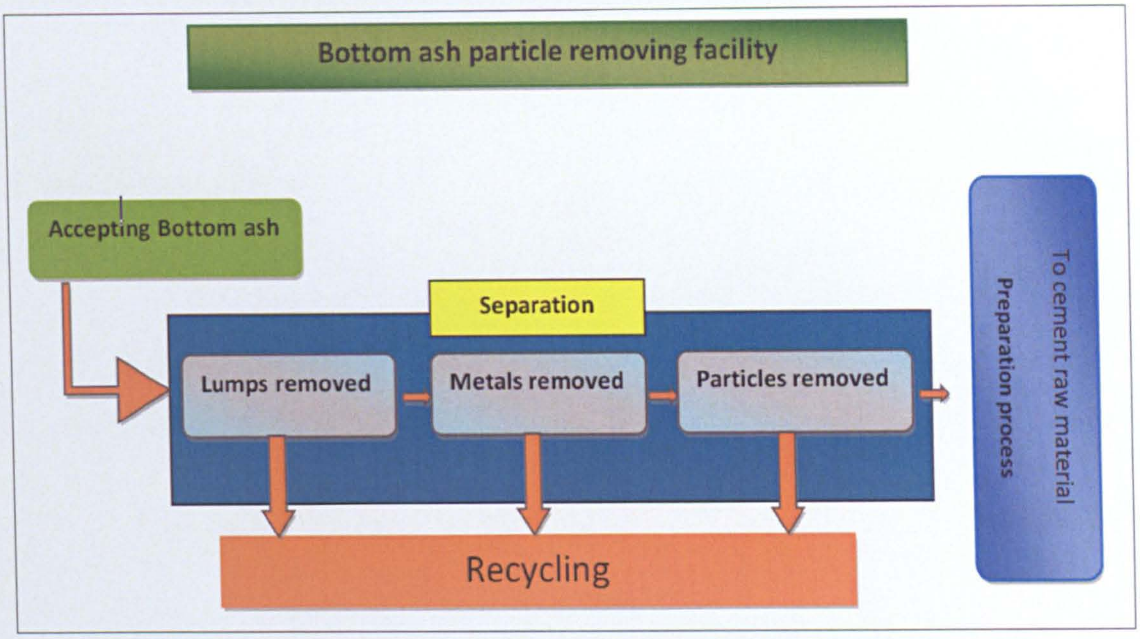


Figure 6.8 Bottom ash washing process

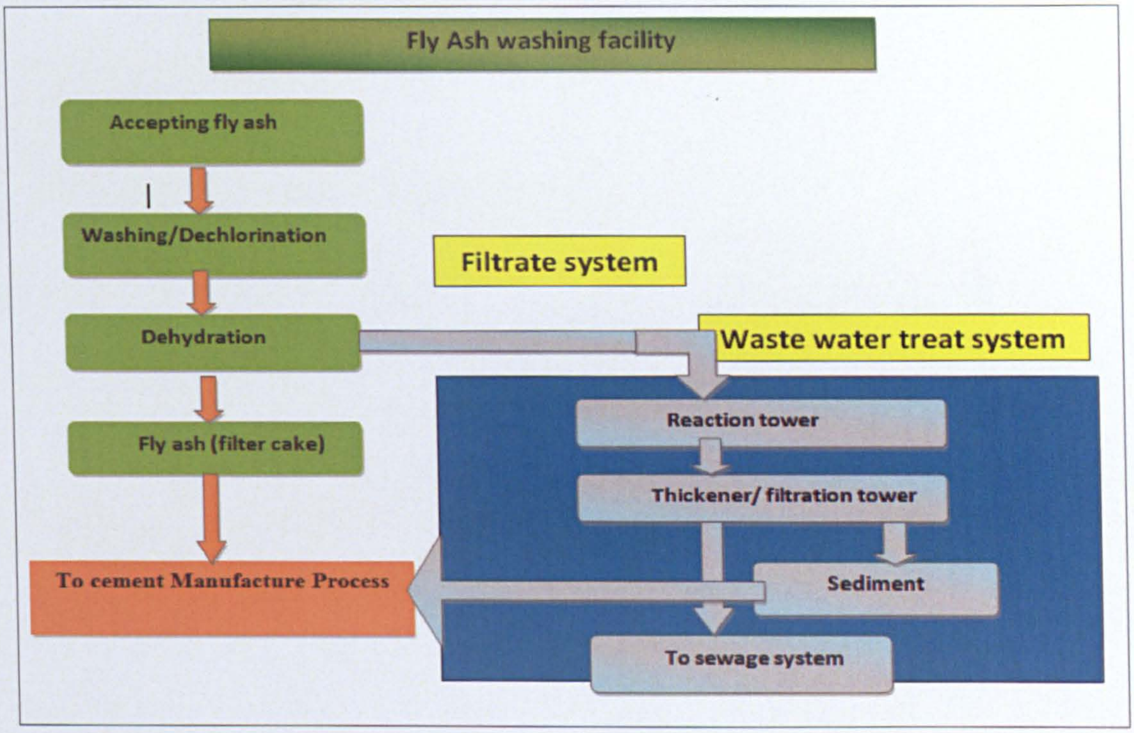


Figure 6.9 Fly Ash washing system and Ecocement plants at Taiheiyo Company

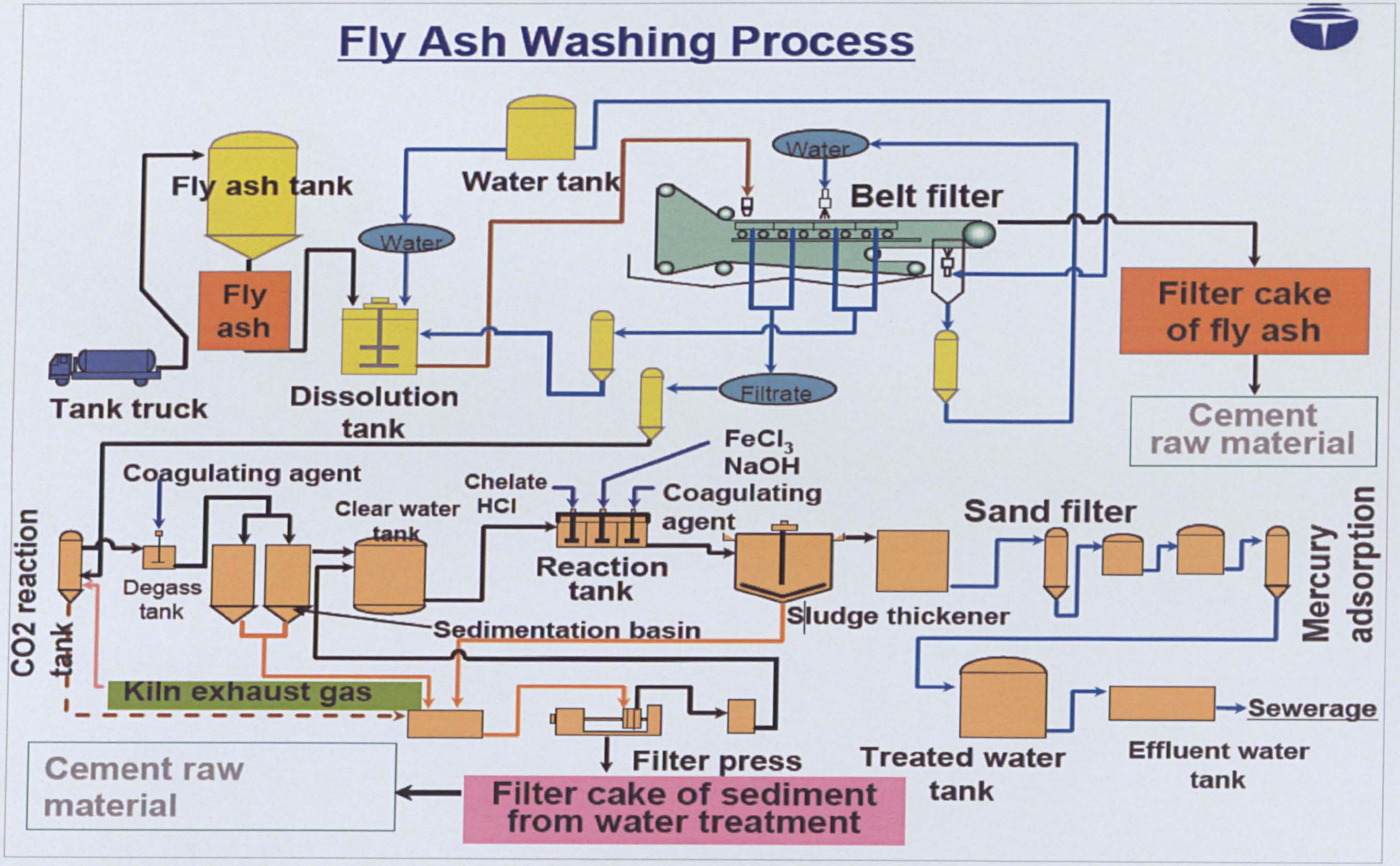


Figure 6.10 Process of the Fly Ash Washing System applied by Taiheiyo Cement Company. (Source: Taiheiyo Corporation 2009).

6.5.1.1 Bottom ash receiving facility

Bottom ash is transported from the municipal incineration plant by road and rail, in special containers which prevent ash emerging, to a Bottom Ash Receiving Facility, in order to eliminate any risk of emitting ash. To remove the large lump, the bottom ash passes over the lump eliminator facility. Following this, the powerful magnetic separator (Figure 6.11) removes metallic items which are then collected and recycled. Next, the ash is screened and sieved by a special sieve and grinder; after removal of the large lumps, the metal in the Bottom ash is converted by the production process and utilized as cement raw material.

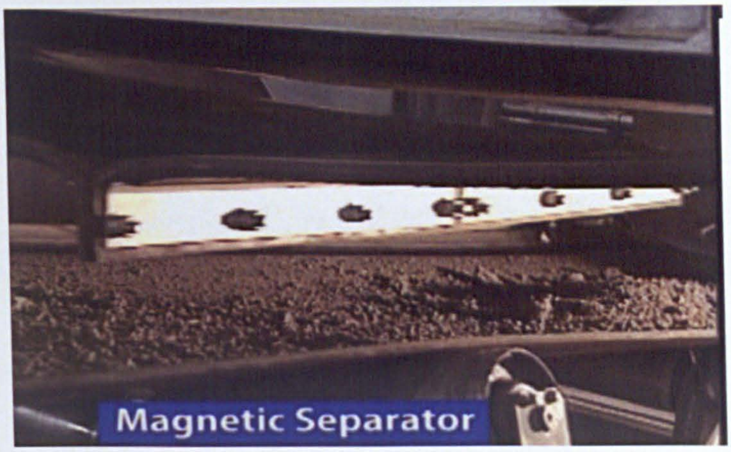


Figure 6.11 The magnetic belt separator used in the Bottom ash system.

6.5.2 Applied Kiln (AK) system

In 1999, development of a system that can accept municipal waste before incineration was launched. This system loads the municipal waste into a rotary digester converted from a redundant cement kiln. The garbage is digested over several days, forming a homogeneous, stable product. The product is then recycled as raw material and safe fuel in an adjacent cement kiln. Figure 6.12 shows the Applied Kiln System's position within the cement works. This technology has been installed in the Saitama plant, which recycles 15,000 tonnes annually of Hidaka city's municipal waste, turning it into resources.

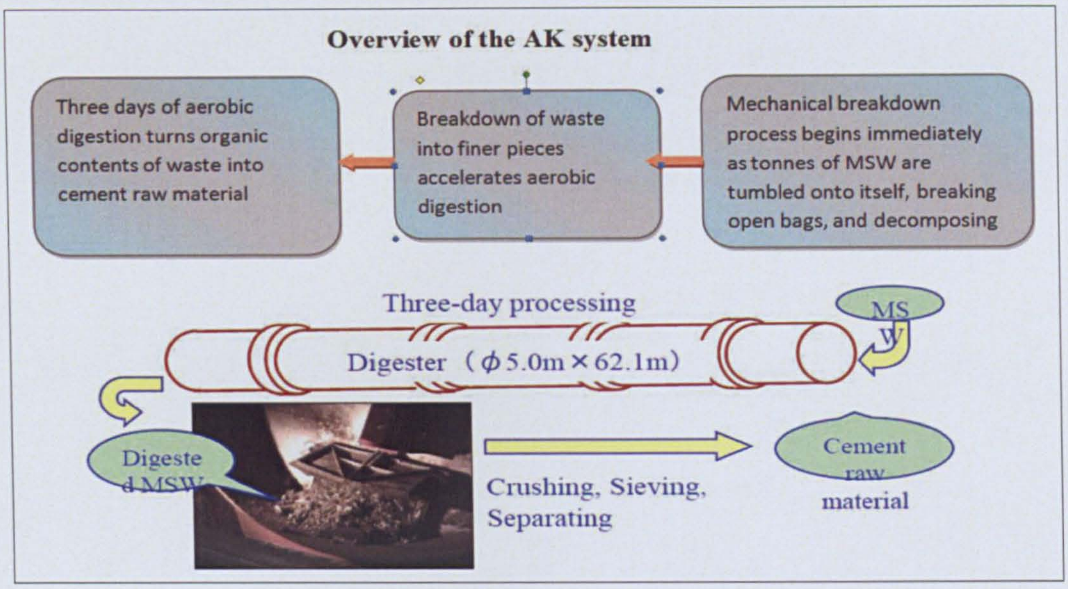


Figure 6.12 AK System operations at Saitama plant, begun in February 2002 (top), and technology for recycling municipal waste (bottom) (Taiheiyo.Cement.company 2010)

The Fly Ash Washing System and the Eco-cement System both recycle municipal waste incineration ash, but the Applied Kiln System (AK System) is different. In that system, municipal waste is utilized in the production of cement without undergoing incineration. The application of this technology to cement production is made possible by modifying an unused kiln in an ordinary Portland cement plant and turning it into a bio-digester. Waste is collected and led directly into the cement plant.

6.5.2.1 Manufacturing process of AFR after leaving the AK system

On arrival of the waste collection at the Receiving Area, it is shut and closed once the waste is loaded down, to avoid any odour or negative smell impact. The waste is transferred by elevator and conveyor and goes directly to the bio-digester. Based on technology especially developed for waste composting, the bio-digester slowly rotates whilst, inside, a bag containing the wastes reduces them to fine fragments (Reports and presentations supplied by Taiheiyo Staff during the site visit). The waste is then biodegraded by the Aerobic Fermentation Process, during which process carbon hydraulic, containing waste such as sugar, and proteins biologically decompose by reaction with oxygen (Decomposition of Carbohydrates, Proteins Decomposition). The gases generated by the bio-digestion process and utilized as combustion air totally categorize without any possibility of any undesirable odours escaping outside. Within 3 days of collection the organic component of the municipal waste which enters the bio-digester is almost completely decomposed and transformed. These recycled materials, now called AFR, are easily handed, sieved, and ground. Following removal of metals and four other objects, the AFR are sieved and ground to a specific size. These materials are then sent to the rotary kiln and utilized as fuel and raw materials for cement production. In the cement manufacturing process, the AFR go to the rotary kiln, along with the main raw materials for cement (limestone, silica, clay, iron), for high-temperature calcination at 1450°C. The ash created in the kiln from the recycled combustion materials is utilized as a substitute for clay to produce the essential ingredient of cement, which is clinker.

The cement kilns are continuously operated at a high temperature, maintained at 1450°C. This temperature eliminates the possibility of Dioxins formation. The AK System is a revolutionary alternative to the municipal waste incineration system. As utilized at Taiheiyo Corporation, it is a recycling system that does not require human control and causes no air pollution risk. The AK System plays an important role in helping to realizing a future recycling-based society.

6.6 Opportunities for environmental impact reduction in cement production at Taiheiyo

Various wastes and by-products generated from other industries are utilized in cement manufacture. The influence of such utilization on the environment is evaluated by using specific Environmental Impact Indicators shown as input and output in Table 6.5 below.

Table 6.5 Levers, inventory and impact of the Environmental Performance of cement production.

Impact	**Inventory**	**Drivers**
Global warming	• CO_2 Kg/tonne cement	• Clinker factor • Energy consumed • Calcination
Depletion of energy resources	• **Crude oil (Kg oil/ tonne cement)**	**Energy consumption (converted into crude oil)**
Depletion of mineral resources	• Natural raw materials Kg/tonne cement	Iron, Calcium, Aluminium, and Silica resource consumption
Shortage of landfills	• **Waste Kg/tonne cement**	• **Waste utilization**

Taiheiyo contributes to environmental conservation by building a recycling-based society and leveraging environmental technologies adopted by the company. At Kumagaya cement plant where the site visit was allowed, different waste materials have been recycled through thermal recycling or raw materials substitution. Table 6.6 shows the usage of each type of waste material or by-product at the Kumagaya cement plant in Japan.

Table 6.6 Utilization of recycled resources at Kumagaya plant, Tokyo.

Raw Material recycling	**Thermal recycling**	**Industrial sources of the recycled materials**
Coal ash	Recycled oil	From electricity industry: fly ash
Water purification plant sludge	Used tyres	From steel industry: blast furnace slag
Sewage sludge	Waste plastic	From other industries: used tyres, used plastic, used Pachinko machines, recycled oil, used oil, construction materials wastes, molding sand.
Construction soil	Waste Pachinko machines	From households: water treatment, sewage sludge and ash, municipal wastes (for eco-cement production), household wastes
Municipal waste incineration	And others	
Other ash (paper, sewage, sludge, etc.)		
Blast furnace slag		
Non ferrous slag		
Molding sand/concrete waste		

6.6.1 Limiting and recycling waste

Cement production requires raw materials that contain the chemical constituents of calcium, silica, aluminium and iron. By being crushed and burned at high temperature in a rotary kiln, the materials undergo chemical reactions and are transformed into compounds having the hydraulic properties required by cement. Therefore, if the waste material contains at least some of the key chemical constituents, it can be used as a raw material for cement. The basic chemical composition of the natural materials, waste and by-products are shown in Table 6.7 Coal is used as a fuel to produce cement, but combustible wastes can act as alternative fuel. The residue from combustion then becomes part of the raw materials and is incorporated in the product. At Taiheiyo, there is an internal acceptable waste manual which makes it possible to decide whether to admit waste after checking it several times. Only waste that has been confirmed as having no negative effect on the quality or production process of the cement or the surrounding environment is admitted, Mr. Tomohiko from the Kumagaya plant explained.

Table 6.7 Basic chemical composition of cement produced at Taiheiyo (%)

		Silicon dioxide SiO_2	**Aluminium Oxide Al_2O_3**	**Ferric Oxide Fe_2O_3**	**Calcium Oxide CaO**	**All alkalis Na_2O**
Ordinary Portland Cement		20-23	3.8-5.8	2.5-3.6	63-65	0.3-0.7
The main natural raw materials	**Lime stone**	4	2	2	47-55	0.2
	Clay	45-80	10-30	3-10	5	2-6
	Silica stone	70-95	2-10	5	2	0.5-3.0
Waste and by-products	**Coal ash**	40-65	10-30	3-10	5-20	0.5-3.0
	Blast furnace slag	20-45	10-20	5	30-60	-0.1-0.5
	Sludge (Sewage sludge)	20-50	20-50	5-15	5-30	1-5
	Molding sand	50-80	5-15	5-15	5	1-5

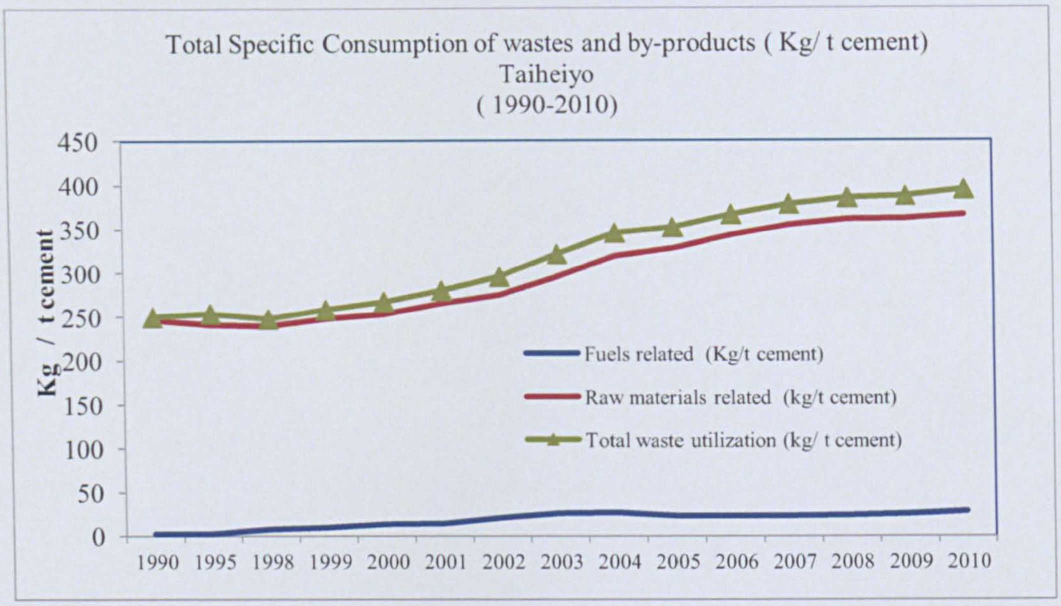


Figure 6.13 Specific waste usages at Taiheiyo with two different utilizations, as ARM and AF.

Despite the fact that cement production at Taiheiyo has decreased over the last 5 years, the volume of waste and by-products used per tonne of cement produced increased to 394.6 Kg/tonne cement in 2010, whilst, in 1990, the average annual volume of waste and by-products accepted by Taiheiyo was 6 Mt as shown above in (Figure 6.13).

(Table 6.8) shows that total waste utilization reached 57% in 2010, higher than 1990 levels, having increased by 8.3% for fuels-related and 48.42 % for raw materials-related usage.

Table 6.8 Improvement in waste consumption in 2010 compared to 1990 levels

Wastes used as AF %	+8.3
Waste used as ARM %	+48.42
Total waste utilization %	+56.721

Taiheiyo has been actively involved in the collection of domestic waste such as ash from municipal waste incinerators and sewage sludge. This positive contribution differentiates Taiheiyo from other cement companies, for whom the chloride content of such wastes was a huge technical barrier to their possible use as materials for cement. However, this problem has been overcome by the development of new technology such as the chloride bypass system and ash washing process.

6.6.3 Raw materials input in cement production and usage of ARM

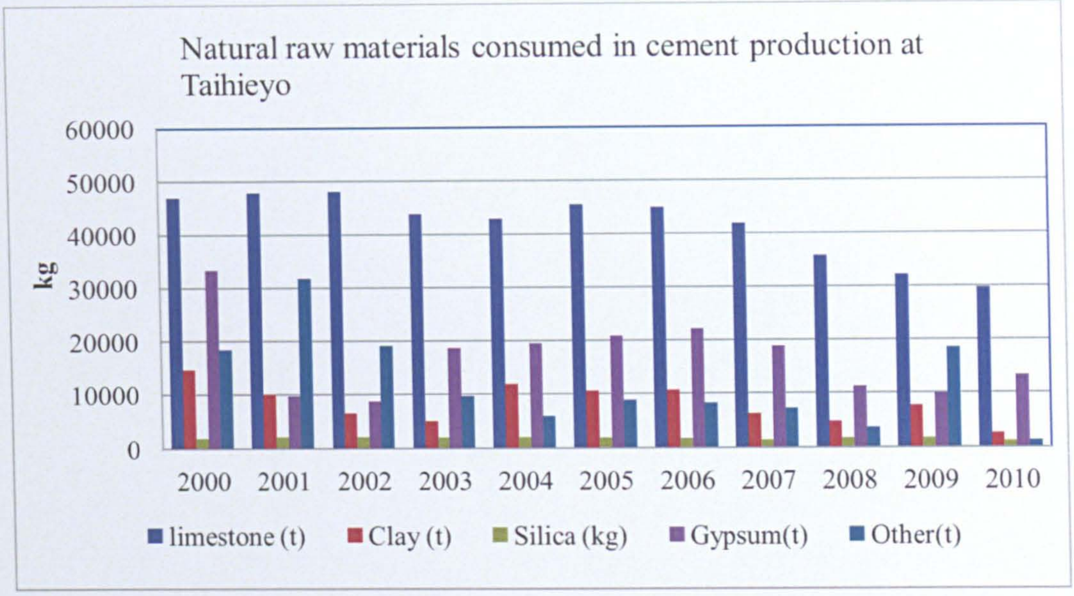


Figure 6.14 Consumption trends of natural raw materials for cement operations at Taiheiyo Cement Company from 2000 to 2010.

In 2010 Taiheiyo produced 125 Mt of cement, which was 38% lower than the 2000 production level of 202 Mt. Figure 6.14 shows that the usage of natural raw materials decreased in 2010 by 54% compared to the 2000 level, going down from 79,614 tonnes to 36,143 tonnes in 2010. Meanwhile, in 2010, 16% of these natural raw materials, especially limestone, the main source of CO_2 emissions, were replaced with ARM such as iron wastes, by-products gypsum, fly and coal ash, blast furnace slag and others containing non-carbonate calcium.

In terms of the calcination process, CO_2 emissions declined by 3.64% in 2010 in comparison with 1990 levels. The specific consumption of natural non-renewable raw materials resources decreased from 1581 Kg/tonne cement in 1990 to 1164 Kg/tonne cement in 2010, as waste utilization increased to reach 240 Kg/tonne cement in 2010.

Figure 6.15 shows types of wastes utilized as ARM and the total waste usage according to the total RM used in Taiheiyo cement operations from 2000 to 2010.

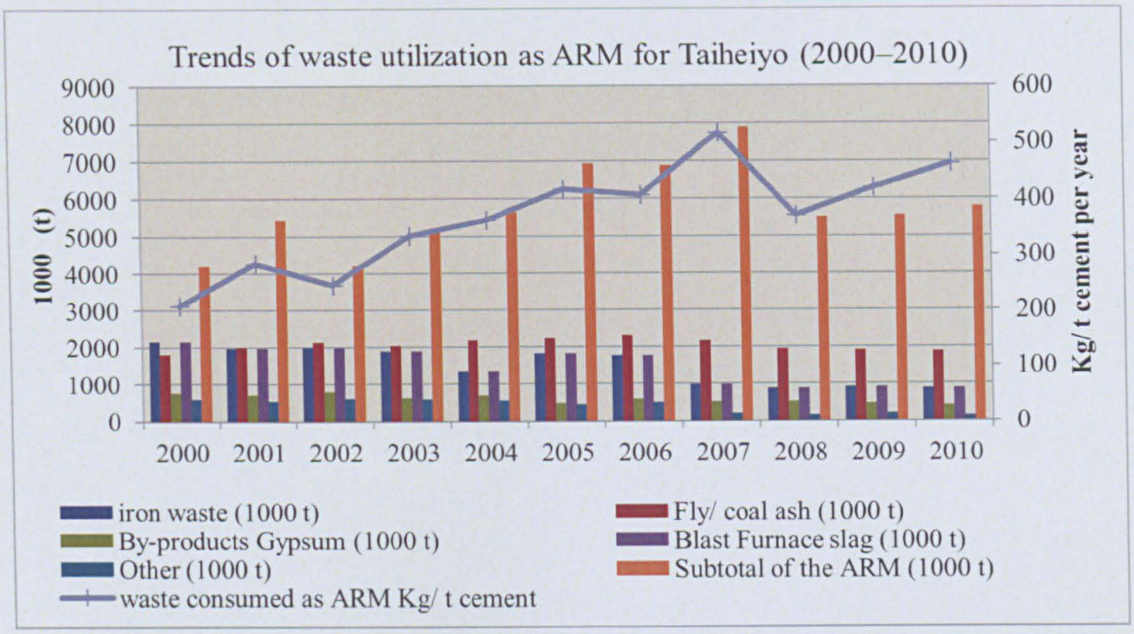


Figure 6.15 Development of various types of waste utilized as ARM in Taiheiyo cement operations.

In 2010 the usage of limestone decreased by 37% from 2000 levels, and the total usage of natural raw materials decreased by 16.02% (Figure 6.16).

In the cement industry, calcination CO_2 exceeds the amount of CO_2 released by energy sources. The biggest change in manufacturing activities in 2010 and fiscal 2000 was the reduced usage of natural clay resources. This mainly reflects the rapid increase, by 3% above 2000 levels, in the amount of coal ash that Taiheiyo Cement collects from thermal power plants for recycling as an alternative to clay. Coal ash utilized in 2010 constitutes 5% of the total raw materials and 3% more than 2000 levels.

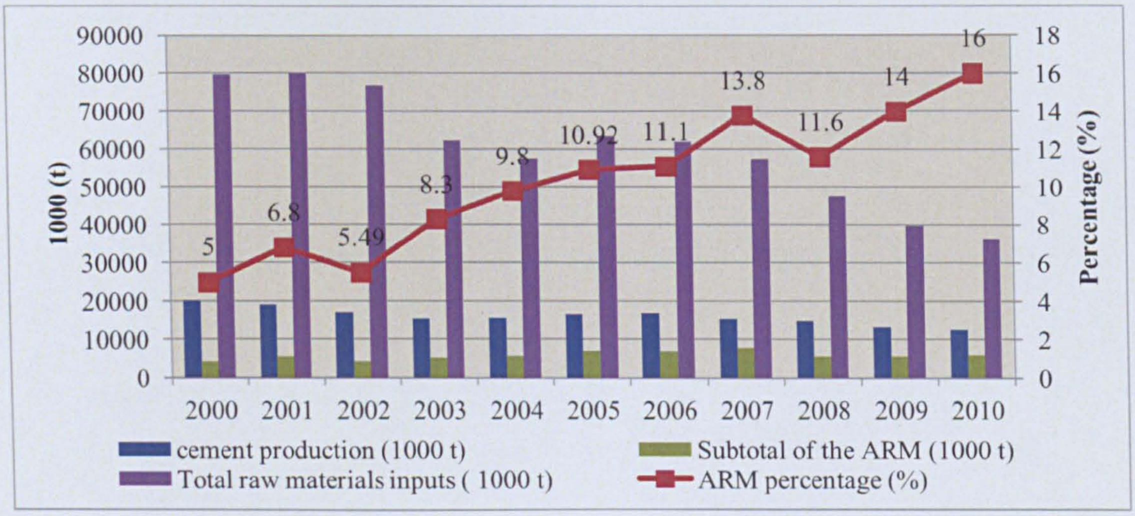


Figure 6.16 Trends in total raw materials used including Natural and ARM, and the changes in ratio of ARM to cement production.

6.6.4 Alternative fuel usage in cement operations at Taiheiyo

Alternative energy resources such as waste, tyres, plastic, oil, and wood are used by Taiheiyo cement operations. In 2010, non-fossil energy and biomass energy utilized constituted 12.7% of all energy use for kilns (Figure 6.17). Furthermore, Taiheiyo planned to use additional different types of alternative energy resources in future (Figure 6.18), such as oil sludge, waste paint, and automobile shredder residue, the handling of which is easier in the cement industry.

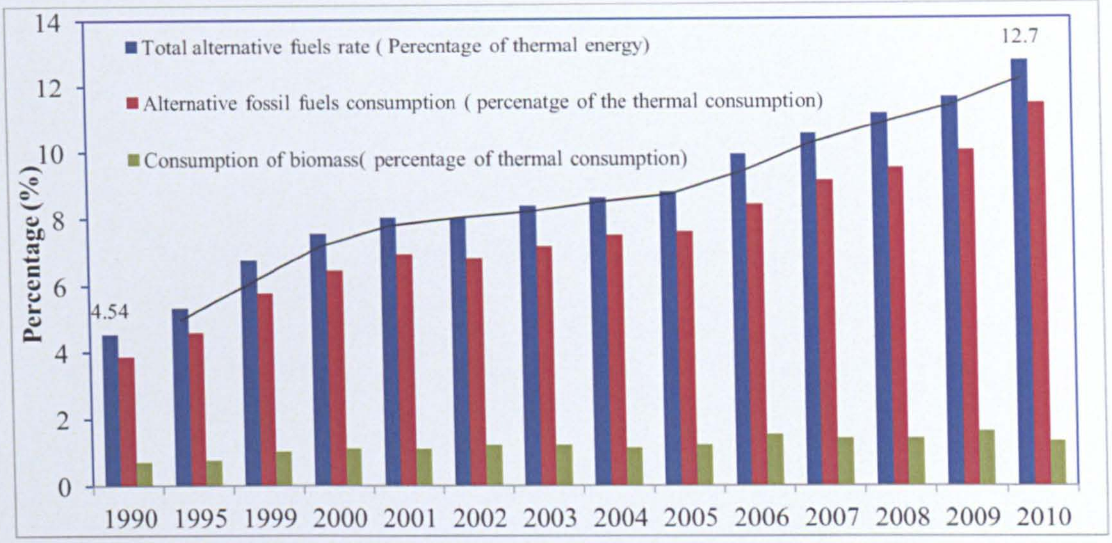


Figure 6.17 Consumption trends in AF from Recycled Fuels including Biomass Waste + Fossil waste as a percentage of thermal consumption (percent Waste).

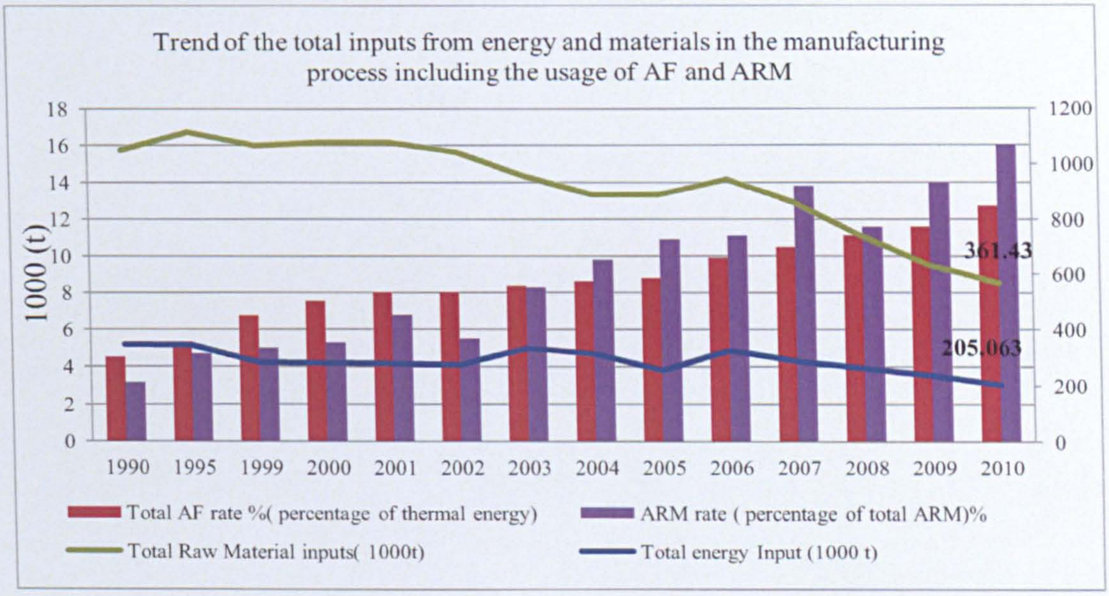


Figure 6.18 Total inputs in the cement manufacturing process for Taiheiyo cement operations.

6.6.5 Assessment of CO_2 emissions trends at Taiheiyo

Taiheiyo is among the principal cement companies who established the Cement Sustainability Initiative in November 1999 as an industry-led sector project of the World Business Council for Sustainable Development (WBCSD). As a CSI commitment, a target was set by Taiheiyo to reduce its specific CO_2 emissions per tonne of cement by 3% from 2000 CO_2 levels, the specific net CO_2 emissions in 2010 being 733 Kg CO_2/ tonne cement, reduced by 3.8% from 762 Kg CO_2/ tonne cement in 2000 (Figure 6.19). The next target is to reduce the CO_2 by 4.5% in 2015 from 2000 levels. These levels were accounted in association with the Cement CO_2 Protocol, which provides Taiheiyo and other CSI members with an effective methodology for calculating and reporting CO_2 emissions (Taiheiyo.Cement.company 2010). However, minimizing the total CO_2 emissions from the process of cement manufacturing is associated with various drivers:

- Minimize quantities of conventional fuels consumed.
- Minimize the usage of limestone, the main raw material used to produce clinker, by replacing it with ARM derived from waste and by-products.
- Minimize the clinker ratio to final product (cement) factor, which will in turn minimize the CO_2 emitted in the calcination process.

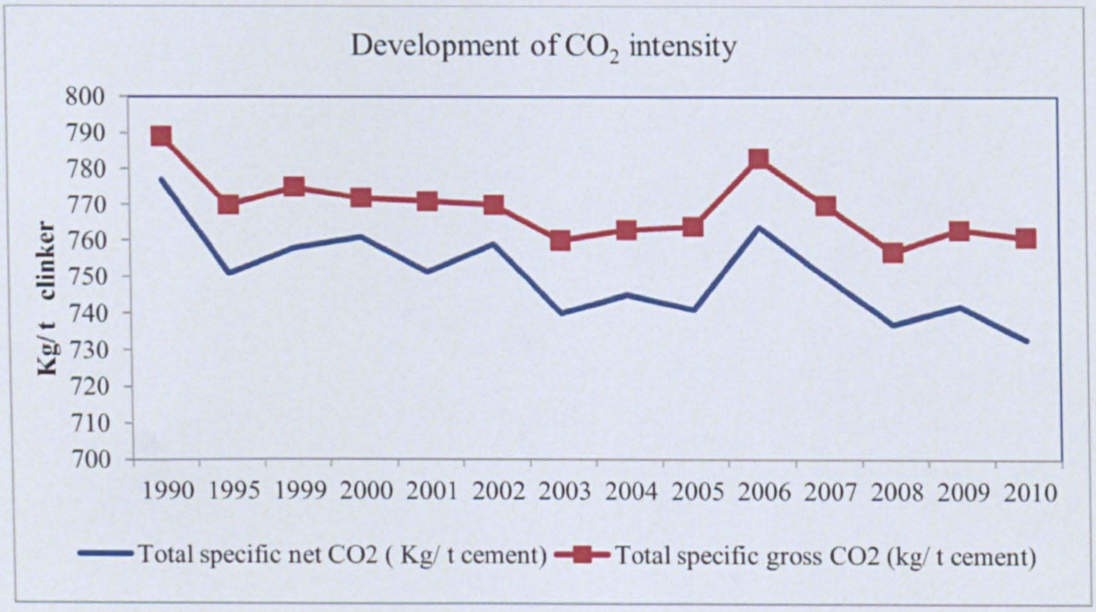


Figure 6.19 Trends in total Gross CO_2 emissions and total Net CO_2 (Kg CO_2/tonne cement) from 1990 to 2010.

Regarding the relation of CO_2 to energy consumption at Taiheiyo, the total CO_2 emitted from fuels combustion (including CO_2 released from purchased electricity, on-site electricity generated, and fuels consumed in kiln) was reduced in 2010 by 2.31% compared to CO_2 emissions in 2000 (Figure 6.20).

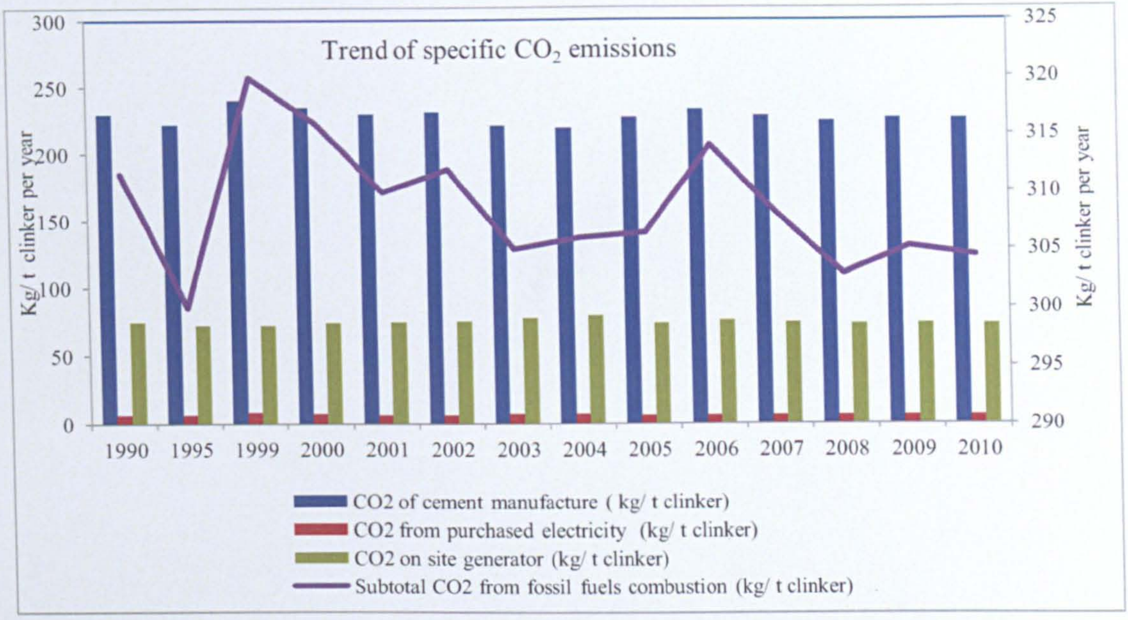


Figure 6.20 Total specific CO_2 emissions reductions from the production process, fuels combustion, electricity consumed and cement manufacture.

According to Taiheiyo sustainability report in 2010 the usage of limestone in cement production decreased by 17.215.939 tonne, from 46.834.908 in 2000 to 29.618.696 tonne in 2010, or a decrease in limestone usage of 36.76% in 2010 compared to 2000. This resulted in decreasing CO_2 emissions by 28% (Figure 6.21), from 10.960.817 tonne of CO_2 to 7.809.010 tonne of CO_2, generated from limestone calcination.

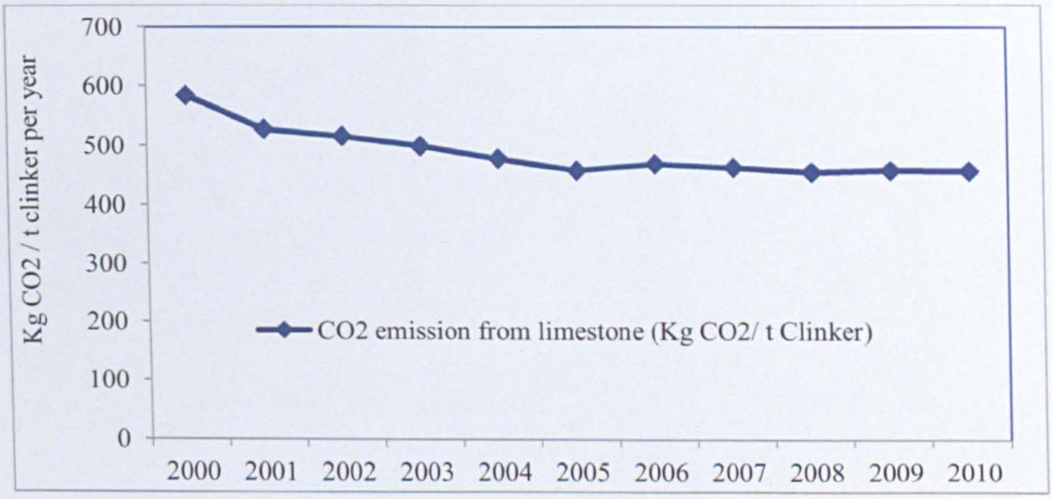


Figure 6.21 Intensity development of CO_2 emissions released from limestone calcinations.

Table 6.9 shows the reduction rates in CO_2 emitted, according to the calculation process, as of 2010 compared to the levels of emissions in 2000. This reduction resulted from minimizing the limestone percentages and the fossil fuels burned by replacing them with minerals components (ARM) and AF.

Table 6.9 CO_2 reduction calculation at Taiheiyo

CO_2 Reduction from limestone (2000–2010)	-0.22 %
CO_2 reduction from reducing the clinker ratio to cement	-1.36 %
CO_2 Reduction from fuel (2000–2010)	-2.31%
Total CO_2 reduction Kg CO_2/tonne clinker (2000–2010)	-3.89%

One of the important techniques for reducing CO_2 emissions per tonne of produced cement is to increase the use of clinker substitutes, such as slag and fly ash, taking into account that the CO_2 emissions from clinker kilns are generated from two sources:

- Limestone calcination, in which the limestone is converted into Calcium Oxide. As a result, an average of 540 Kg CO_2 is constantly emitted through this process, and 10 Kg CO_2/tonne clinker are released from the organic material in limestone.
- Emissions from fossil fuels combustion. The thermal efficiency affects only about 40% of CO_2 emissions which are related to the consumed fuel.

Figure 6.22 shows the trends in Taiheiyo's clinker to cement ratio, which decreased to 85.7% in 2010 from 88.2% in 2000. That is, the total gross CO_2 emissions per tonne of clinker were 772 Kg CO_2/tonne clinker in 2000, declining by 1.42 to 761 Kg CO_2/tonne clinker in 2010.

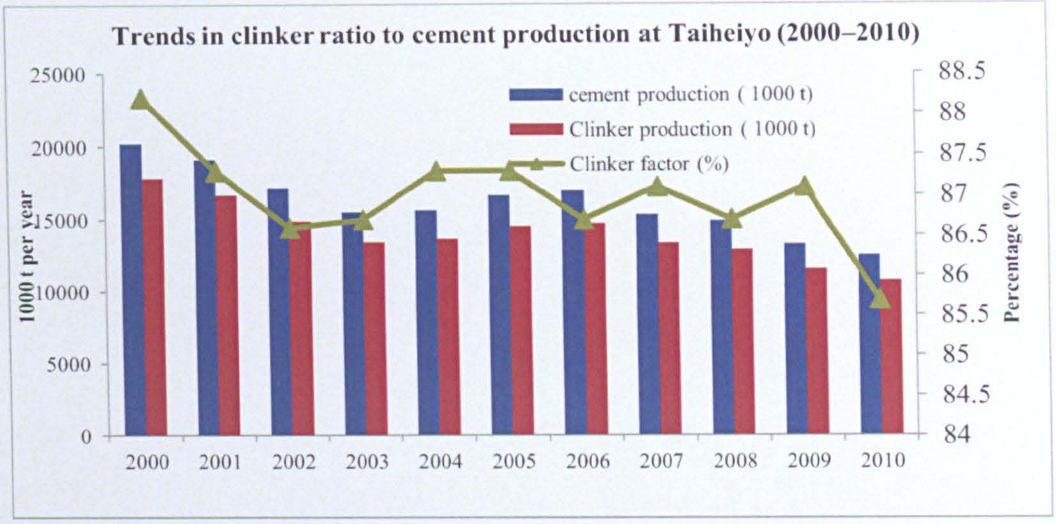


Figure 6.22 Trends in cement production, clinker production, and clinker factor at Taiheiyo.

In Figure 6.23, the performance curve illustrates the improvement in gross CO_2 emissions per tonne of clinker as the curve moves downward from 2000 to 2010, showing progressive improvement in clinker performance (lower CO_2 emissions in 2010 in comparison with 2000).

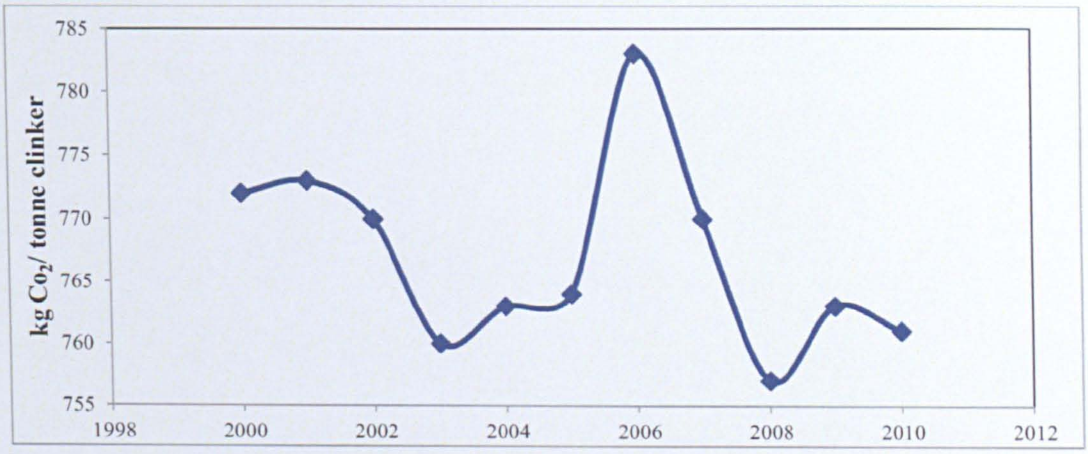


Figure 6.23 Trends in CO_2 efficiency released from clinker at Taiheiyo (Kg/ tonne clinker).

Therefore, in order to produce low CO_2 cement, different strategies are employed by Taiheiyo: improvement of the quality of raw meal and the development of new technologies in clinker sintering at low temperature; efficient and effective application of AFR in place of virgin natural resources; and broad high-volume replacement of clinker with supplementary cementitious materials (SCMs); as well as highly efficient application of innovative technologies in cement production. This means reducing OPC usage to the greatest extent possible without compromising the expected properties and performance of these different cementitious materials in their final form.

6.7 Results of the environmental impact assessment and environmental economic benefit evaluation for Taiheiyo cement operations

The purpose of this chapter has been to assess the environmental impact of cement operations at Taiheiyo Cement Company, taking into account the social and economic benefits of the environmental improvements. The focus was on evaluating the reductions in CO_2 emissions and examining the levers leading to the reduction that has occurred over the last two decades, from 1990 to 2010. It was found that Taiheiyo has contributed substantially to the reduction in natural resources consumption by waste recycling, as well as to the reduction in social costs and environmental impact, which has fallen year-upon-year through the company's processing of waste. Also, as a key centre of waste processing for other industries and companies, Taiheiyo has become indispensable to Japanese industries and local communities. The company's plants reduced social costs by levels higher than those of 2000, with 12.4 billion yen. This was achieved by using waste generated from other industries, which had considerable economic effects.

To summarise, the results of recycling waste and by-products at Taiheiyo Corporation for cement works are presented in (Figure 6.24) and (Table 6.10), showing that waste disposal at Taiheiyo cement plants:

- Reduces CO_2 by cutting down coal consumption and usage, so that the CO_2 emissions declined by a figure equal to 8985 1000 tonne of CO_2 lower than the CO_2 in 2000 by 29 Kg CO_2 emissions per tonne of cement produced. The percentage of the CO_2 emissions improvement equals 3, 8% saving on the 2000 level.
- Increases the life of limited landfills by increasing the amount of waste utilization used for cement production, from 199 Kg in 2000 to 249 Kg in 2010 of waste per tonne of produced cementitious materials.

- Recycles waste for raw materials, the subtotal of the Alternative raw materials having increased by 37% from 4220 (1000 tonne) in 2000 to 5784 (1000 tonne) in 2010. The proportion of total ARM within the total RM consumed in 2010 was 16%.

- Recovers energy from waste utilization, as the total specific energy consumption was reduced by 9.62% in 2010 compared to 2000 levels, going down from 3637 MJ/tonne clinker in 2000 to 3287 MJ/tonne clinker in 2010. However, most of this energy saving comes from reducing the Specific energy consumption (fossil fuels used on-site power + purchased electricity) by 630 MJ/tonne clinker, going down from 1047 MJ/tonne clinker in 2000 to 417 MJ/tonne clinker in 2010, rather than the Specific heat consumption from fossil fuels; here the MJ/tonne clinker increased in 2010 above 2000 levels by 280 MJ/tonne clinker. In terms of Taiheiyo's recent environmental performance, the average fuel intensity required for clinker production showed an overall reported decline to 3 GJ/tonne clinker, electricity use declined to100 kWh/tonne cement, whilst the shares of coal, gas, and alternative fuels were 70%, 5%, and 25% by 2010. In addition, Taylor showed that Japan was the most energy-efficient country. The energy requirement per tonne of clinker ranged between 3.3 GJ/tonne clinker in 1990 to 3 GJ/tonne clinker in 2005, these requirements in both these two years being the lowest worldwide (Michael Tylor 2006).

- The ratio of clinker to cement production decreased from 88.2% in 2000 to 85.7% in 2010, which is still considered a high ratio for the clinker factor and the main source of CO_2 emissions. According to Taylor, Tam, and Gielen in 2006, the same high clinker factor was found in Japan as a country. This ratio ranged from 93% in 1980 down to 91% in 2005. Globally, Japan was considered the biggest producer of clinker material (C.A. Hendriks 2004).

Table 6.10 Environmental Impact Assessment and the socioeconomic benefit evaluation (2000-2010)

EPI	**2000**	**2010**	**Changes**
Total specific Net CO_2 emissions Kg/ tonne cement	762	733	-29
Reduction and improvement of the total specific Net CO_2 emissions %			-3.81
Improvement of the Clinker factor %	88.2	85.7	-2.5
Specific heat consumption from fossil fuels (MJ/ tonne clinker)	2590	2870	280
Specific energy consumption (fossil fuels used on site power + purchased electricity) (MJ/tonne clinker)	1047	417	-630
Total specific energy consumption(M J/ tonne clinker)	**3637**	**3287**	**-350**
Improvement of total Specific energy consumption %			-9.62
Total AF rate(percentage of the thermal energy) %	7.55	12.7	5.15
Subtotal of the ARM (%)	4220	5784	37.06
Total raw materials inputs (%)	79614	36143	-54.60%
ARM rate percentage of the total ARM %	5.3	16	11.7
Water consumption 1000 m3/ tonne cement	324.251	180.233	-144.018
Economic benefit evaluation (EEBE) (1000 million ¥)	53.8	66.2	12.4

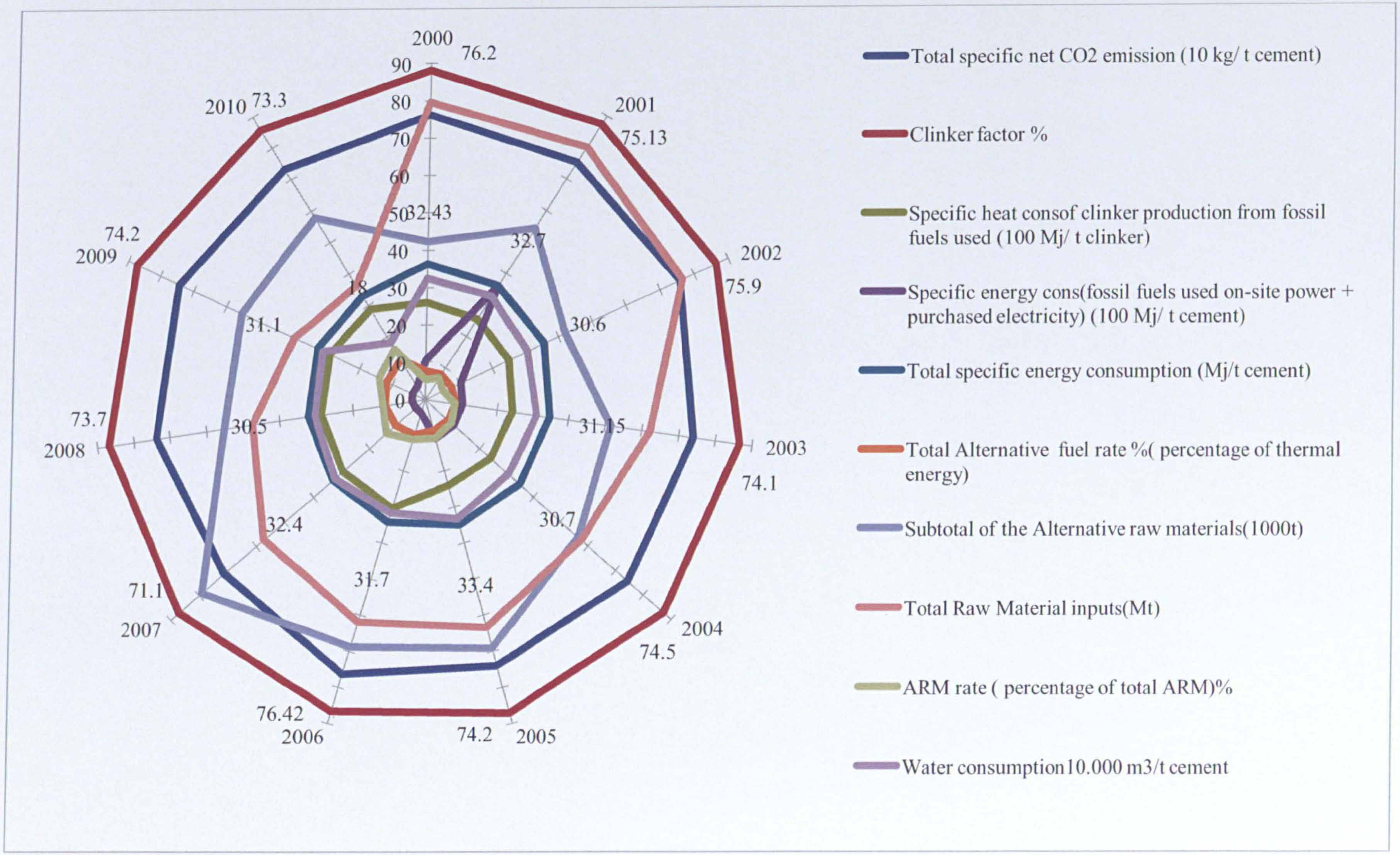


Figure 6.24 Environmental Impact Assessment for cement operations at Taiheiyo

Chapter 7

The Comparison of Environmental Performances

7.1 Introduction

According to research carried out by Bhushan Jangla I, benchmarking is a well-designed and established tool for performance comparison.

Effective benchmarking enables researchers to quantify the performance of a specific industry, compare this performance to others in the same industrial sector, identify the gaps in different performances, and define the actions required to close these gaps (Wood 2008).

The benchmark is a measurement with which to identify best performance practices (Trimble 2012)Benchmarking is defined by the American Productivity & Quality Centre as "the process of identifying, understanding, and adapting outstanding practices and processes from organizations anywhere in the world to help your organization improve its performance"(Trimble 2012).

This study employed two types of benchmarking, the first related to a self-independent level, and the second based on benchmarking the three companies in comparison with each other.

The self-independent benchmark assessed each company's performance and the progress of the sustainable development approach at each of the three firms over 20 years of cement operations.

The performance indicators included within this study are applicable to existing cement operations, as well as to future development, as was explained in Chapters 3, 4, and 5, in which the assessment relied strongly on the performance indicators. These indicators have been used to:

- Assess how environmentally sustainable the cement operations worldwide are, taking into account economic and social aspects.
- Identify indicators with poor performance on various spatial and time scales.
- Identify the best performance regarding CO_2 emissions and resource conservation.
- Make recommendations for improving the performance of existing cement works after determining the scale of key indicators influencing these operations.

Essential indicators have been set in this research, based on WBCSD initiatives, projects and guidelines, as well as on the availability of the data.

Data were collected throughout operational site visits granted by these companies, and by interviewing people in charge of AFR usage, cement process management, and CO_2 emissions control.

It was possible to collect most of the required data. On the other hand, the research takes into account that the chosen case studies were of major international cement companies.

Therefore, individual self-performance comparison and benchmarking have been conducted by this research in addition to wider industrial benchmarking in relation to other cement companies.

According to Michael Clark in 2003, a benchmarking tool is a logical first stage in strengthening initiative for any performance, activity or operation. It measures current performance against appropriate peers and identifies the gap between current performance and best practices (Clark 2003).

This allows reasonable objectives and targets to be set and plans to be drafted in order to achieve those objectives and targets.

The goals and targets of performance benchmarking for the selected cement companies can be summarized as:

- Identify cement world best performance.
- Determine the drivers for this performance and the areas that are causing the most trouble.
- Quantify the differences and gaps between the performances of the benchmarkers.
- Specify the best performance cement company, especially considering that the three cement companies have been deemed the best performance firms by the WBCSD organization.
- Set up a foundation for further performance improvement.

Comparison against worldwide cement production and cement production processes allows the progress of the cement sector to be monitored and targets for cement production improvement to be identified (Clark 2003).

The benchmark was used not only to determine the opportunities for reducing CO_2 released from cement production but also to compare the performances of cement companies with each other.

Furthermore, benchmarking usage in cement production activities offers the ability to broadly test the positive and negative aspects of the best performance cement companies, as well as the basis on which to create processes with less environmental impact, especially in terms of CO_2 emissions linked to the process analysed.

However, the benchmarking tool was used in particular to estimate the reduced environmental impact of current cement operations at Lafarge, Holcim, and Taiheiyo, and to determine new opportunities for efficient cement production with low CO_2 emissions.

"Eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity throughout the making process to a level at least in line with the Earth's estimated carrying capacity" as defined for first by the WBCSD in Antwerp workshop held in 1993(Popoff 2000).

Based on the review and analysis of Sustainable Development Reports for Lafarge, Holcim, and Taiheiyo from 1990 to 2010, a procedure for developing comparable environmental performance indicators has been described.

These indicators have a strong influence on full identification and benchmarking of the complete manufacturing process in each company, the technologies followed, amount of thermal energy consumed, various types of fuels and alternative fuels, raw materials and alternative raw materials used, and amount of clinker produced per tonne of final cement product.

The indicators were determined by gathering and processing benchmarking performance data covering 20 years, from Lafarge, Holcim, and Taiheiyo.

In terms of energy efficiency, the most efficient performance was that of Taiheiyo, the Japanese cement company, as its total specific energy consumption in 2010 was 3.287 MJ/tonne clinker in comparison to Lafarge's and Holcim's energy consumption, with total electricity consumption of 259.69 MJ/tonne clinker coming from consumption of 772.893 MWh, divided into 595.957 MWh from purchased power and 176.936 MWh from on site generation by burning fossil fuels.

7.2 Opportunities for manufacturing cements based on MSWIA as RM in the UK

Municipal solid waste incinerator ash (MSWIA) can be used in different applications to make novel cements.

It can be used as the major component of an alkali-activated pozzolanic cement, as major raw material within a novel process for producing traditional Portland cement, or within Eco-cement production as explored at Taiheiyo.

According to the British Cement Association (BCA) in 2006, there would be no obvious technical barriers to Eco-cement production in the UK.

But currently, MSWIA is in short and irregular supply in the UK, apart from the public perception issue which could arise, far outweighing other considerations. Therefore, the possibility of producing Portland cement by this familiar process in the present social, economic and regulatory conditions would be low.

Furthermore investigations have been conducted by this research with a view to examining and identifying the best environmental practices in regard of less CO_2 emissions and other environmental impacts, and its applicability in the UK.

7.2.1 The Eco-cement system potential in the UK in response to its manufacturing at Taiheiyo Company

Eco-cement is a new, innovative type of cement, produced outside the conventional cement plant and there is a wide potential to be produced in the UK.

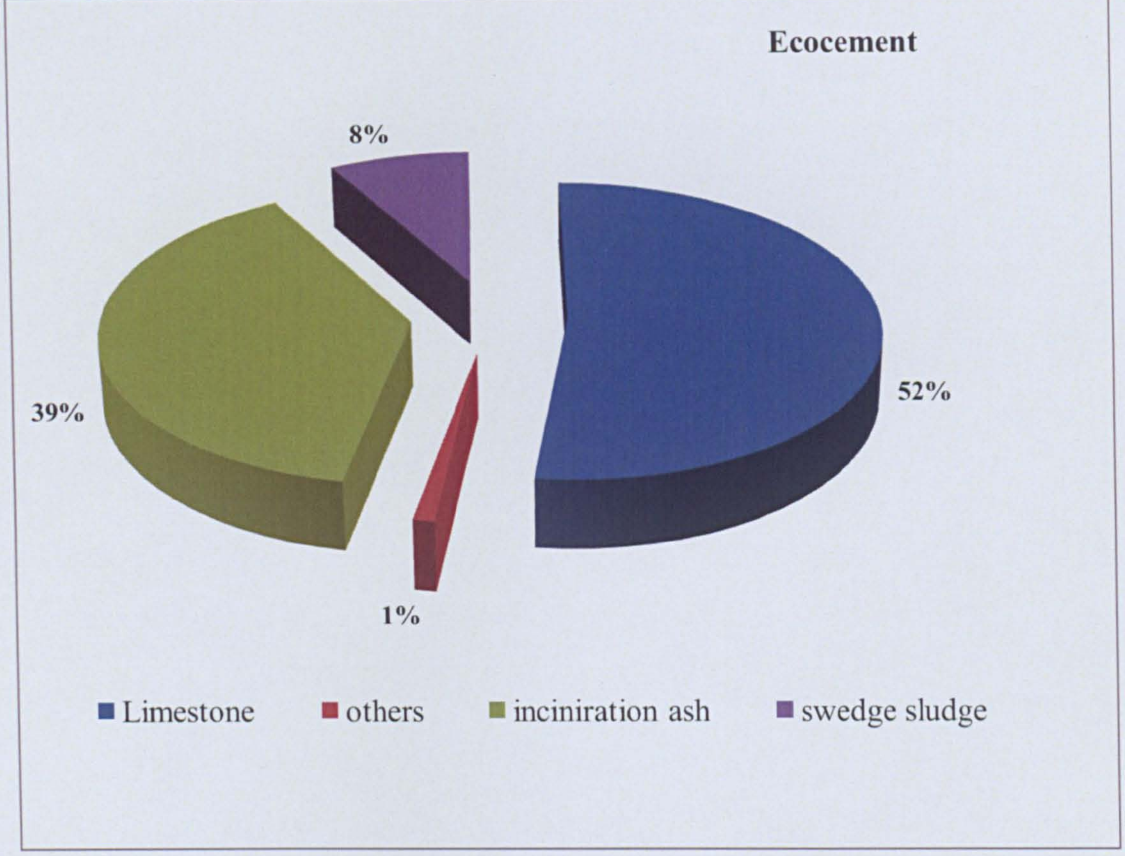
The basic raw materials of Eco-cement are ash and soot from municipal waste incinerators, as a large quantity of the main raw materials of ordinary Portland cement (limestone, clay, iron and gypsum) are replaced by up to 50% of incineration ash from municipal waste.

Burnable wastes such as waste oil, plastics, and RDF (refuse-derived fuel) can also be used as Eco-cement fuel.

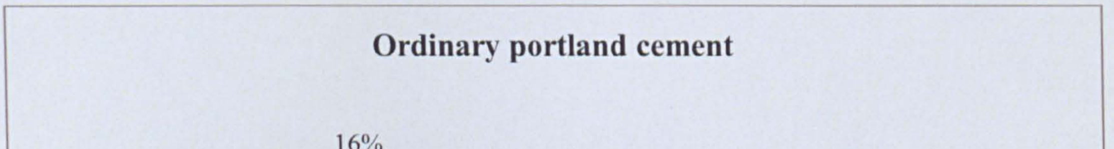
There are two types of Eco-cement, the ordinary type, which gives the same performance as ordinary portland cement (OPC) and is used in reinforced concrete structures, and the fast-hardening type, which is used in non-reinforced concrete structures (Taiheiyo.Cement.company 2008).

The first Eco-cement plant was launched in Ichihara city in April 2001 (Taiheiyo.Cement.company 2002). It is designed to produce 110,000 tonnes of Eco-cement annually, using wastes from 2.5 million residents. Another plant, completed in 2004 in Hinode town, Tokyo, is designed to produce 160,000 tonnes of Eco-cement annually, utilizing wastes from the 4.5 million residents of Tokyo Metropolis. Eco-cement received certification by the Japanese Industrial Standards (JIS) in 2002.

Figures 7.1(a) and 7.1(b) show the raw materials impact created by replacing the natural resources used for Ordinary Portland Cement (limestone, clay, etc.) with incineration ash for the Eco-cement process.



Figures 7.1 (a) Comparison of raw materials for Ordinary Portland Cement and Eco-cement.



Figures 7.1 (b) Comparison of raw materials for Ordinary Portland Cement and Eco-cement

7.2.1.1 Process of eco-cement production and its properties

The process of Eco-cement manufacture is mainly the same as that of Ordinary Portland Cement. Eco-cement has same components as OPC (alite C3S, belite C2S, calcium aluminate C3A, calcium alumino-ferrite C4AF, and calcium sulfate) (Figure 7.2). But incineration ash has a high chloride content together with a small amount of heavy metals. These contaminated substances for cement clinker, unsuitable for use as raw materials in OPC, are vaporized through the sintering process and caught as kiln dust in the bag filter. Then the heavy metals are removed from the kiln dust through a metal recovery process, to be delivered later on as useful metals in refineries (Shimoda 2000).

This enables Eco-cement to save precious metal resources and enhance environmental protection by offering a comprehensive recycling system for industrial and municipal waste.

Accordingly, Eco-cement contributes to prolonging the life of landfill sites and making municipal waste harmless through a process free from secondary waste generation, equipped with a comprehensive environmental protection system including flue gas purification and heavy metal recovery, so that the chlorine within is converted into a useful component of a special cement clinker mineral (C11A7CaCl2), which has a very fast-hardening quality (Shimoda 2000).

At the same time, a reduction in CO_2 emissions can be achieved by the Eco-cement process through its lesser use of limestone and the low temperature required for burning. Figure 7.2 show the process of Eco-cement production.

Eco-cement is usually produced in a separate plant, in which the Bottom ash and Fly ash go to the incineration ash receptacle, are recycled, and become the main component of the Eco-cement product. Fly ash and Bottom ash are blended with limestone, processed in the same way as Ordinary cement and burned in a rotary kiln. Each 1 tonne of Eco-cement produced consumes 5.5 tonnes of waste.

7.2.2 Ash washing process

An innovative system has been developed by Japanese cement companies and can be applied in the UK to utilize ash and soot emitted from municipal waste incinerators as a raw material for the production of general cement. In particular, the "ash washing process" which uses water to remove chlorides from soot has made it possible to convert ash from incinerators into a cement raw material.

7.2.3 Conversion of municipal solid waste into material resources

Another system is effective for reducing CO_2 emissions. This system is is already used in UK to utilize municipal solid waste in form of its collection without prior incineration. In this system, the waste is placed in a waste recycling kiln, converted from an unused cement kiln, and fermented. Then the waste is converted into a stable product to be used as fuel and raw materials for cement production in an adjacent cement kiln.

7.2.4 Sludge recycling

Recycled water purification sludge generated from water supply facilities is transported to cement work sites and used as a cement raw material (WBCSD-Japan 2001).

7.2.5 Recycling waste plastics

A large volume of waste plastic is collected by the cement industry from the plastics industry. It uses shredders to reduce the waste plastic fragments to a uniform size; the fragments then become an auxiliary fuel source for cement production.

7.2.6 Recycling used tyres

The illegal dumping of used tyres has become a social problem but cement plants are utilizing them as an auxiliary fuel in the cement production process (G.C.Bye 1999). The high combustion temperature in the kiln eliminates the possibility of air pollution from the processing of the tyres.

In addition, their metallic elements are incorporated as a cement ingredient so that no secondary waste is created.

7.2.7 Contaminated soil treatment

For soil contaminated with dioxins, heavy metals, organic solvents or oils, cement production offers high temperature treatment services which allow soils from contaminated sites to be treated safely and recycled.

7.2.8 Blast furnace slag

Among industrial wastes and by-products, the substance used in the greatest volume by the cement industry is blast furnace slag. Blast furnaces produce pig iron and discharge as slag; those ingredients (other than molten iron), together with the ash content in coke and limestone, are used as auxiliary materials. The cement industry receives more than 60% of the huge volume of slag discharged by the steel industry and uses it as cement raw materials and additives.

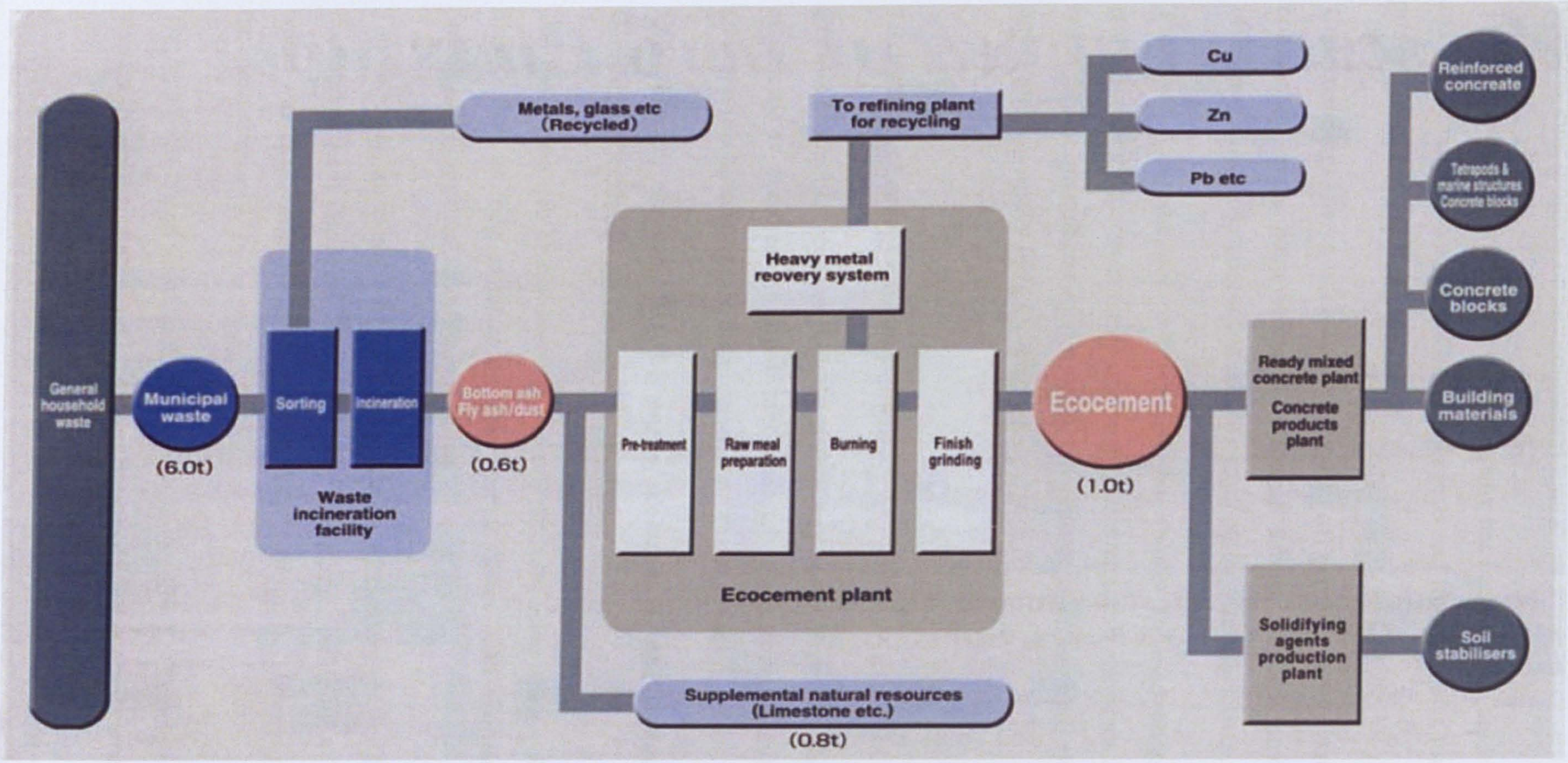


Figure 7.2 The scheduled process flow of Eco-cement production (Taiheiyo.Cement.company 2008)

7.3 Environmental performance indicators

The process of cement production releases various GHGs and pollutants. It consumes resources such as raw materials, fossil fuels and water, thus contributing to the scarcity of these resources.

Therefore, the cement industry as an energy-intensive process leaves a major footprint on the environment, creating different challenges related to conservation of resources, including natural raw materials and energy.

According to the International Energy Agency, the existing potential for alternative fuels and raw materials (AFR) usage is what has made energy efficiency improvement and AFR usage the main levers for reducing CO_2 emissions from cement operations over the last decade (Schneider et al 2011).

The environmental indicators specified by the research can assess the environmental outputs and footprints from cement production on the level of each company, as was done in the 4th, 5th, and 6th chapters.

The present chapter benchmarks the environmental performances among the three identified case studies by using the same Environmental Performance Indicators applied in the previous chapters to compare the performances of Taiheiyo, Lafarge, and Holcim, and to identify the company with the least CO_2 emissions and the drivers used to lower these emissions.

The data on the amount of CO_2 emissions for each company were collected from the yearly published reports on sustainable development in line with the companies' commitments to the WBCSD organization and from interviews with people at the CO_2 emissions department for each company.

These emissions were reported as specific Net and Gross emissions including the direct and indirect CO_2 released.

The research takes into account the direct CO_2 emissions which come from sources owned by the company and the indirect emissions which come from external sources but have consequences affecting the activities of the indicated company.

The most relevant environmental performance indicators have been identified by the research with the aim of highlighting areas for priority action, monitoring, and benchmarking progress on environmental issues.

The environmental progress of each company has been investigated in previous chapters and will be compared and rated to identify gaps and find formulas for environmental protection with fewer footprints.

Understanding the environmental impact of cement production is an important component in the achievement of financial return, social contribution, and energy efficiency, when pursuing minimal environmental impact objectives.

Therefore it is essential to determine that impact by evaluating the inputs to the manufacturing process in terms of energy consumed, raw materials and water used, and the different manufacturing techniques followed, together with the outputs of GHG emissions, especially the CO_2 released.

7.3.1 Thermal energy consumption

Cement production requires both thermal energy and electricity. Energy consumption as electricity is required to grind raw materials (limestone, blending materials, and additives) so as to complete the process of producing cement.

This research showed that the energy demand in clinker production has been significantly reduced over the last two decades.

The best technique levels over the last two decades were always for Taiheiyo cement plants, due to their reliance on dry process kilns with multistage preheater and precalciner (European.Commission 2010).

Theoretically, an average of 1.75 MJ/Kg of thermal energy is needed to burn 1 Kg of Portland cement (Bolwerk 2004). In 2010 at Lafarge, usage of AF including biomass waste was 12%, comprising 9% waste and 2.7% biomass. These percentages were % of the thermal energy.

The heat recovery of waste including biomass was 439.2 MJ/tonne cement, and the total waste utilization related to fuel replacement was 26.9 Kg/tonne cement.

In 2000 the energy consumption rate at Taiheiyo was 3637 MJ/tonne cement, divided into consumption of fossil fuels used in cement production (2590 MJ/tonne cement), fossil fuels used in onsite power generation (816 MJ/tonne cement), and purchased electricity (231 MJ/tonne cement).

This means that the total fuels required for burning on site to produce cement equals 3406 MJ/tonne cement, as against the required electricity, which was 231 MJ/tonne cement.

Taiheiyo was the most efficient energy consumer compared to Lafarge and Holcim, but the consumption rate of fuels at Taiheiyo was greater than that of Lafarge or Holcim, whilst the electricity consumed was less.

In 2010, the total ratio of energy consumption at Taiheiyo was 3287 MJ/tonne cement coming from fossil fuels consumption to 2870 MJ/tonne cement and 417 MJ/tonne cement from onsite power generation and purchased electricity.

In 2007 at Taiheiyo, the ratio of total energy consumption was 3302 MJ/tonne cement, including the total consumption rate of electricity which was 347 MJ/tonne cement coming from both purchased electricity and onsite power generation.

Taiheiyo's energy consumption rate is the most efficient of those of the three cement companies and it consists of around two-thirds of electricity generated from burning fuels on site.

This results in increasing the ratio of fuels consumed which have high components of carbon, leading to increased emissions of CO_2. Thus, although Taiheiyo is the most efficient energy consuming company compared to Lafarge and Holcim, the amount of specific net CO_2 emissions is still the highest as the result of burning more fossil fuels than are burned at Lafarge or Holcim.

The thermal substation rate at Taiheiyo in 2000 was 8.6%, derived from 7.5% thermal substation for fossil fuels and 1.1% biomass.

However, these rates increased in 2010, when the total AF was 12.7%, 11.4% from replacement of conventional fuels by waste utilization and 1.3% from biomass usage.

Lafarge was the biggest electricity consumer, using 728 MJ/tonne cement compared to Holcim's consumption of 551 MJ/tonne cement and Taiheiyo's 231 MJ/tonne cement.

In 2000 the total specific thermal consumption was 3723 MJ/tonne cement, coming from 472 MJ/tonne cement in electricity consumption and 3389 MJ/tonne cement in fossil fuels consumption.

These rates improved in 2010, decreasing to total thermal consumption of 3660 MJ/tonne cement, comprising 417MJ/tonne cement from electricity consumption and 3440 MJ/tonne cement from fossil fuels.

However, the consumption of electricity at Lafarge decreased by 11% in 2010 compared with 2000 levels whilst the amount of fossil fuels burned in 2010 slightly increased, by 1.5% over the 2000 level.

Since 2000, the usage of AF at Lafarge has been the main method for reducing the usage of traditional fossil fuels and the amount of CO_2 emissions released, since cement activities require substantial quantities of energy at every step of the production process.

The thermal substation rate for Lafarge at 2000 was 7.7%, including 6.8% coming from alternative fossil fuels and 0.9% from biomass usage.

In 2000, over 6 millions of oil equivalent in the form of fuel oil, electricity, petcock, coal and other fuels were consumed in Lafarge cement operations.

These AF rates improved in 2010, increasing to around 12.1%, consisting of 9% from waste materials and by-products, representing the substation rates for fossil fuels, and 2.1% from biomass.

According to Holcim, its thermal energy consumption improved by 11% compared to 1990 levels. Thermal energy consumption was 3900 MJ/tonne cement in 2000, down from 4300 MJ/tonne cement in 1990.

This improvement was due to the closure of 11 old energy-intensive cement plants and construction of more efficient ones containing rotary dry kilns.

For Holcim, thermal consumption rates decreased from 3900 MJ/tonne cement in 2000, to achieve second best performance among the three companies by consuming 3555 MJ/tonne cement.

Whilst in 2000, Holcim was the biggest electricity consumer, with thermal energy from electricity amounting to 450 MJ/tonne cement, in 2010 its rate went down to 367 MJ/tonne cement, making it the second largest electricity consumer.

The thermal substitution rate increased from 9% in 2000, when Holcim registered the best performance regarding AF; this rate of AF included 7.3% thermal heating derived from waste utilization and 1.7% from biomass.

Holcim was rated the same as Lafarge in 2010 in regard to AF, as the thermal energy replacement reached 12.1% in that year, comprising 10% derived from waste and 2.1% from biomass.

To summarise, energy consumption rates at the three companies indicates that Taiheiyo has the best performance regarding energy efficiency, even the rates for thermal replacement being the best over the last ten years.

However, the rate of energy consumed at Taiheiyo was basically dependent on fuels burning. Hence the energy consumption rate was 2590 MJ/tonne cement, including 816 MJ/tonne cement coming from fossil fuels used in onsite power generators and 231 MJ/tonne cement from purchased electricity.

That means that the consumption of electricity was 1047 MJ/tonne cement, but the other 816 MJ/tonne came from fossil fuels burning rather than from the 231 MJ/tonne cement which was purchased.

These high rates of fossil fuels consumption and fuel burning, in addition to the high ratio of clinker to cement production, affects the CO_2 emitted by Taiheiyo Cement Company, which was the highest CO_2 emitter over the last ten years.

Tables (7.1, 7.2, and 7.3) and figures (7.3, 7.4, 7.5) identify the key Environmental Performance Indicators for 2000 with which to assess the environmental impact of cement operations at these three cement companies with special reference to CO_2 emissions, which equalled 251208 Million MJ.

Cement production in 2000 was 67.466266.9 Mt of cement produced. That means that the total specific energy consumption per tonne was 3723.461179 MJ/ t cement.

7.3.2 Waste consumption

In 2000, Taiheiyo's waste utilization rate was the best, at around 2.66.92 Kg/tonne cement, including 13.9 Kg/tonne cement related fuels and 253 Kg/tonne cement related raw materials replacement.

However, this was not the situation in 2010, when Taiheiyo registered the second best performance in waste utilization, after Lafarge which was the biggest consumer of wastes and by-products.

The total waste utilization for Taiheiyo in 2010 was 394.6 Kg/tonne cement, including 27.9 Kg/tonne cement for fuels replacement and 366.6 Kg/tonne cement for raw materials substitution.

According to Holcim, its ratio of AF in 2010 was 12%, representing the thermal substitution rate of total thermal energy consumed.

This percentage stands for 445 MJ/tonne cement derived from burning 2.8 Mt of waste, which equals total waste utilization of 384.451 Kg/tonne cement.

This rate was the third compared to those of Lafarge and Taiheiyo in 2010, and includes 34.48 Kg/tonne cement from waste-related fuels replacement and 319.582 Kg/tonne cement from replacement of raw materials.

This amount of waste was co-processed, saving 2.1 Mt of coal. In 2007, 2.8 Mt of waste was recovered by Holcim to provide 12% of the total thermal energy.

The usage of natural raw materials was 194.4 Mt, cement production was 161.6 Mt of cement, and the consumption of ARM was 26.9 Mt.

At Lafarge in 2000, a wide range of waste products related to fuels replacement was used to save conventional energy consumption and to obtain more efficient energy, as discussed in Chapter 4.

Lafarge was rated second in 2000 in recycling waste materials, compared to Taiheiyo and Holcim. The total consumption of waste was 233.27 Kg/tonne cement, coming from 31.12 Kg/tonne cement related fuels and 204.2 Kg/tonne cement related raw materials. These rates increased, giving Lafarge the best performance regarding waste utilization in 2010.

The total consumption of waste in 2010 was 513.39 Kg/ tonne cement, comprising 31.9 Kg/tonne cement waste-related fuels and 462.051 Kg/tonne cement waste-related raw materials.

In 2007, Lafarge's consumption of recycled waste materials such as blast furnace slag and pulverized fly ash as raw feed or as an addition to clinker conserved natural resources.

19.5 Mt of waste was used as alternative raw materials (ARM). This practice reduced the cost of cement production and contributed to the decrease in CO_2 emissions from 2000 levels. Lafarge cement production in 2007 was 143 Mt, with an AF substitution rate of 10.56% of total thermal energy consumed in that year.

This led to:

10.56% (AF)* 3861 MJ/tonne cement = 407.72 MJ/tonne cement of which heat recovery is derived from 7.7 Mt of biomass, wastes, and by-products.

(7.7 Mt / 143 Mt) *1000= 53.85 Kg/ tonne cement

This means that Lafarge recovered 53.84 Kg/tonne cement in 2007, which is considered, among consumption rates, the best performance regarding waste recycling and utilization compared to Taiheiyo and Holcim.

Waste utilization provides an important environmental service to the community and industry at the same time.

It is important to understand how the role of cement manufacturing practice in economizing on the natural process, by reusing and recycling waste materials as fuels and raw materials and choosing those with low environmental impacts, minimizes harmful environmental effects and conserves natural resources for the next generation's consumption.

7.3.3 Clinker factor

Clinker can be replaced by other materials, called secondary cementitious material, to form various kinds of cement.

Lowering the clinker factor reduces the amount of fuel needed per tonne of cement. In addition, clinker replacement by suitable waste materials and industrial by-products reduces the amount of natural raw materials required.

Suitable materials for use as clinker substitutes include fly ash from power generation and blast furnace slag from iron production.

However, ordinary Portland cement is the most fundamental kind of cement, with a clinker ratio of 95%, the remaining 5% coming from the addition of gypsum to the clinker produced.

The clinker factor has the predominant effect on CO_2 emissions. Therefore, lowering the clinker factor is the essential driver in reducing carbon dioxide intensity and natural resources consumption, including that of natural fuels and raw materials required per tonne of cement, by partially replacing the clinker used in the composite cement production process with mineral components that have binding properties.

The investigation of the three cement companies showed that the clinker ratio to cement production for Taiheiyo was always the highest factor compared with Lafarge and Holcim.

Taiheiyo was the biggest clinker producer, with a factor of 88.2% in 2000. Meanwhile the clinker factor (CLF) for Lafarge and Holcim was approximately the same, around 80% of cement production in 2000 in each of these two companies.

The high rate of fuels burned and the percentage of clinker factor at Taiheiyo affected the CO_2 emission efficiency, making Taiheiyo the highest CO_2 emitter compared to Lafarge and Holcim, although Taiheiyo was the most energy-efficient company.

This ratio went down in 2007, from 88.2% in 2000 to 87.1% in 2007 and 85.7% in 2010. However, these rates are still considered too high when measured against the clinker ratio for either Holcim or Lafarge.

In this respect, Holcim showed the lowest clinker ratio across the identified comparison years. In most of these years, Holcim and Lafarge had competitive clinker ratios.

In 2000, Holcim's clinker ratio was 79.8%; it declined to 72.6% in 2007, then 71.5% in 2010.

Lafarge had approximately the same ratios as Holcim in 2000 and 2010, which were 80% and 72% respectively.

A difference between Lafarge and Holcim emerged in 2007, when the clinker ratio at Lafarge, 77%, was higher than that at Holcim.

As a result, the high ratio at Taiheiyo has a negative effect on CO_2 emissions efficiency, increasing the CO_2 released per tonne of cement produced. In particular, according to Graeme Moir in his contribution to the Advanced Concrete Technology , every 100 tonnes of produced clinker consumes 12 tonnes of coal (John Newman 2003).

Coal is considered the main fuel required for clinker making. Additionally, each tonne of clinker requires 1.57 tonne of raw materials, including limestone, the principal raw material.

In other words, the more clinker is produced, the more energy and raw materials are consumed and the more CO_2 emissions are released.

7.2.4 CO_2 emissions: "specific net CO_2 emissions and gross CO_2 emissions"

Cement CO_2 emissions come primarily from the following stages in the process of cement manufacturing:

- 50% from the chemical process of clinker production
- 40% from burning fossil fuels in kilns
- 5% of indirect emissions from purchased electricity
- 5% from the transportation of the final product of cement.

Investigations performed by this research showed that these emissions can be lowered by applying various levers, such as:

- Reducing the amount of clinker used per tonne of cement produced
- Replacing fossil fuels
- Improving energy efficiency and reducing kiln dust disposal.

These levers were assessed in previous chapters and are considered the main tools for reducing the amount of CO_2 emissions. Benchmarking the three cement companies' performances in regard to CO_2 showed that Lafarge had the best performance with the least specific CO_2 over the last ten years, declining from 667.29 Kg CO_2/tonne cement in 2000 to 606.4 Kg CO_2/tonne cement in 2010.

For Holcim, in 2000 the Absolute Gross emissions were 55 million tonnes CO_2, and the Absolute Net emissions were 53.8 tonne CO_2. The Specific Net CO_2 emissions were 690 Kg CO_2/tonne cement, and the Specific Gross CO_2 emissions were 710 Kg/tonne cement. It is important to mention here that, despite an increase in the amount of Holcim's cement production in 2000 by 67% over 1990, the increment in the Absolute Net CO_2 was only 34%. In 1990, the Absolute Gross CO_2 emissions were 39 million tonnes CO_2 and the Absolute Net CO_2 was 38 million tonnes CO_2.

The benchmark Radar Figures (7.3, 7.4, 7.5) and Tables as shown below (7.1, 7.2, and 7.3) are based on data, collected and analysed from the three cement companies, on Specific Net and Gross CO_2 emissions, specific thermal energy consumption and types of energy consumed including the traditional fuels and electricity, the substation percentage of alternative thermal energy consumption, clinker factors and percentage of natural raw materials replacement by ARM, waste utilization percentage relating to heat recovery and raw materials replacement, and water consumption.

Table 7.1 EPI (Environmental performance indicators in 2000) as found by this research	Taiheiyo	Holcim	Lafarge
Total specific net CO_2 (10 Kg/tonne cement)	74.5	68.9	66.729
Total specific gross CO_2 (10 Kg/tonne cement)	76.1	70.6	66.12
Total specific energy consumption (100 MJ/tonne cement	36.37	39	37.2346
Specific energy cons (electricity) (10 MJ/tonne cement)	2.31	4.5	3.73
Specific energy cons (fossil fuels) (100 MJ/tonne cement)	34.06	34.5	33.504
AF % (thermal substation rate %)	7.55	9	7.7
Alternative fossil fuels consumption (percentage of the thermal consumption) (%)	6.45	7.5	6.3
Consumption of biomass (thermal percentage consumption) (%)	1.1	1.5	1.4
ARM %	5.3	8	8.2
Clinker factor %	88.2	79.8	80
Water consumption (10 L/tonne/y)	32.43	28.1	43.5
Total Waste utilization (10 Kg/tonne cement)	26.69	14.415	23.327
Fuel related (Kg/tonne cement)	13.9	18.5512	31.12667
RM related (10 Kg/tonne cement)	25.3	12.56	20.42

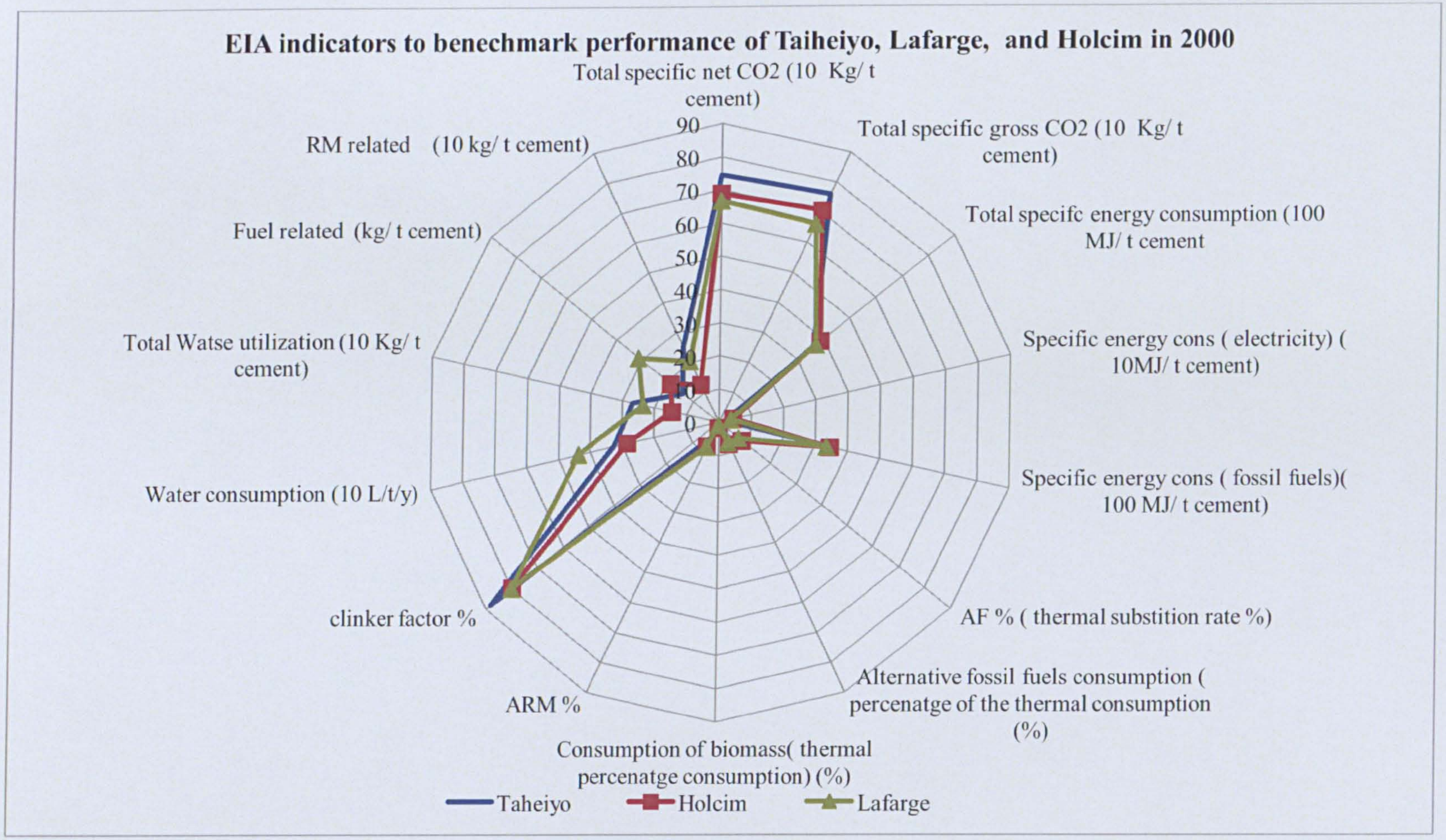


Figure 7.3 EIA indicators to benchmark performance of Taiheiyo, Lafarge, and Holcim in 2000 as found by this research

Table 7.2 EPI (Environmental performance indicators in 2007) as found by this research	Taiheiyo	Holcim	Lafarge
Total specific net CO_2 (10 Kg/tonne cement)	75.1	64.4	64.7
Total specific gross CO_2 (10 Kg/tonne cement)	77.1	66.4	65.4
Total specific energy consumption (100 MJ/tonne cement)	33.02	34.03	38.61
Specific energy cons (electricity) (10 MJ/tonne cement)	31.6	37.8	47.2
Specific energy cons (fossil fuels) (100 MJ/tonne cement)	29.55	30.25	33.89
AF % (thermal substation rate (%)	10.5	11.7	8.8
Consumption of waste (thermal consumption rate) (%)	9.1	10	6.9
Consumption of biomass (thermal percentage consumption) (%)	1.4	1.7	1.9
ARM %	13.8	10	10.56
Clinker factor %	87.1	72.6	77
Water consumption (10 L/tonne/y)	21.18	33	34.3
Total Waste utilization (10 Kg/tonne cement)	37.81	18.3787	19.0172
Fuel related (Kg/tonne cement)	22.9	17.3267	53.846
RM related (10 Kg/tonne cement)	35.52	16.646	13.6326

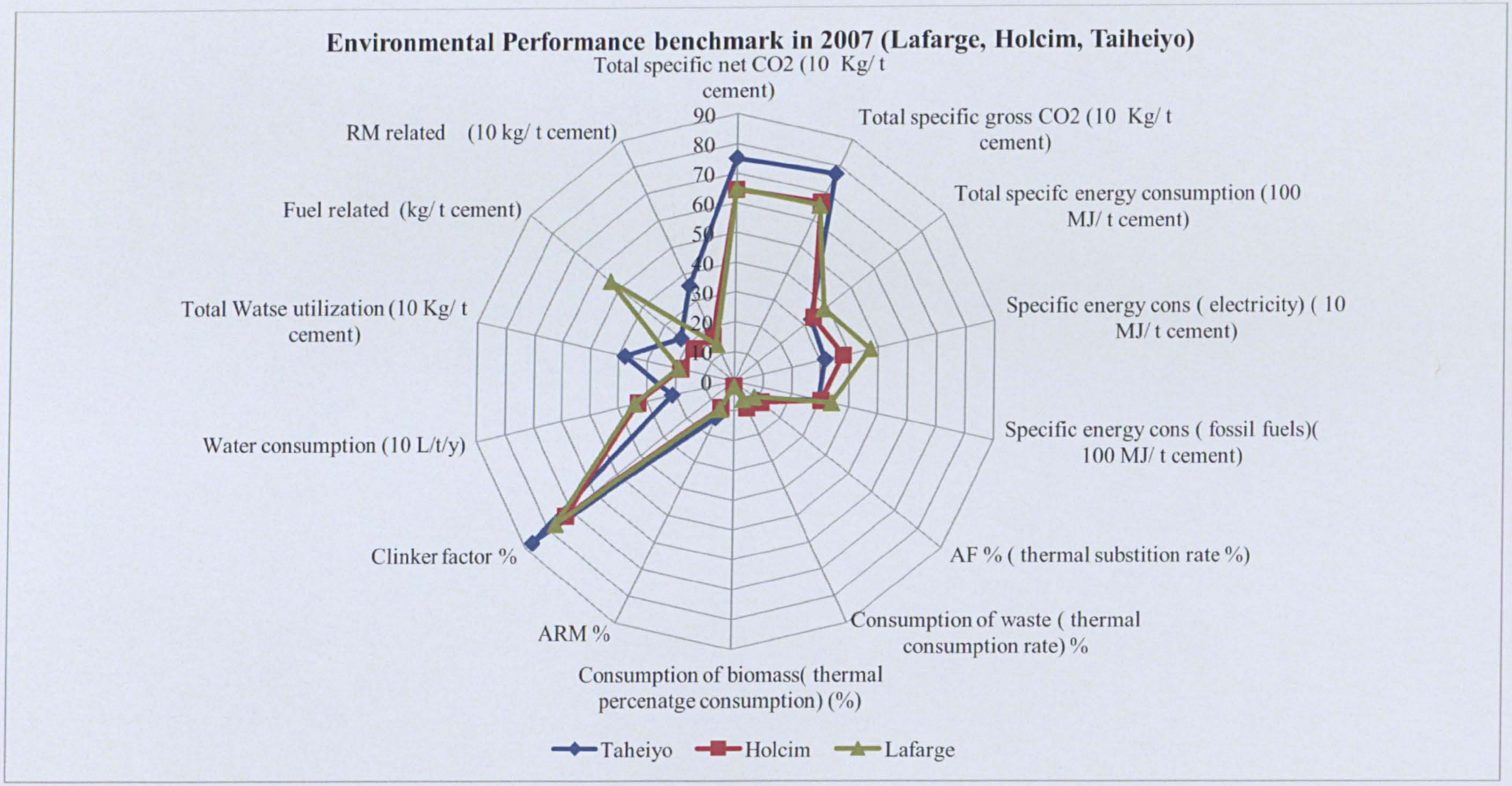


Figure 7.4 Environmental Performance benchmark in 2007 (Lafarge, Holcim, Taiheiyo) as found by this research

Table 7.3 EPI (Environmental performance indicators in 2010) as found by this research	Taiheiyo	Holcim	Lafarge
Total specific net CO_2 (10 Kg/tonne cement)	73.3	62.9	60.6
Total specific gross CO_2 (10 Kg/tonne cement)	76.1	64.8	62.6
Total specific energy consumption (100 MJ/tonne cement)	32.87	35.55	36.6
Specific energy cons (electricity) (100 MJ/tonne cement)	2.22	3.67	4.17
Specific energy cons (fossil fuels) (100 MJ/tonne cement)	30.68	29.25	34.404
AF % (thermal substation rate %)	12.7	12.1	12
Consumption of waste (thermal consumption rate) (%)	11.4	10	9.00
Consumption of biomass (thermal percentage consumption) (%)	1.3	2	2.7
ARM %	16	13	11.4
Clinker factor %	85.7	71.5	72
Water consumption (10 l/tonne/y)	14.77	30	47.9
Total Waste utilization (10 Kg/tonne cement)	39.46	23.8587	51.339
Fuel related (Kg/tonne cement)	27.9	34.4869	31.9
RM related (10 Kg/tonne cement)	36.66	3.19582	46.2051

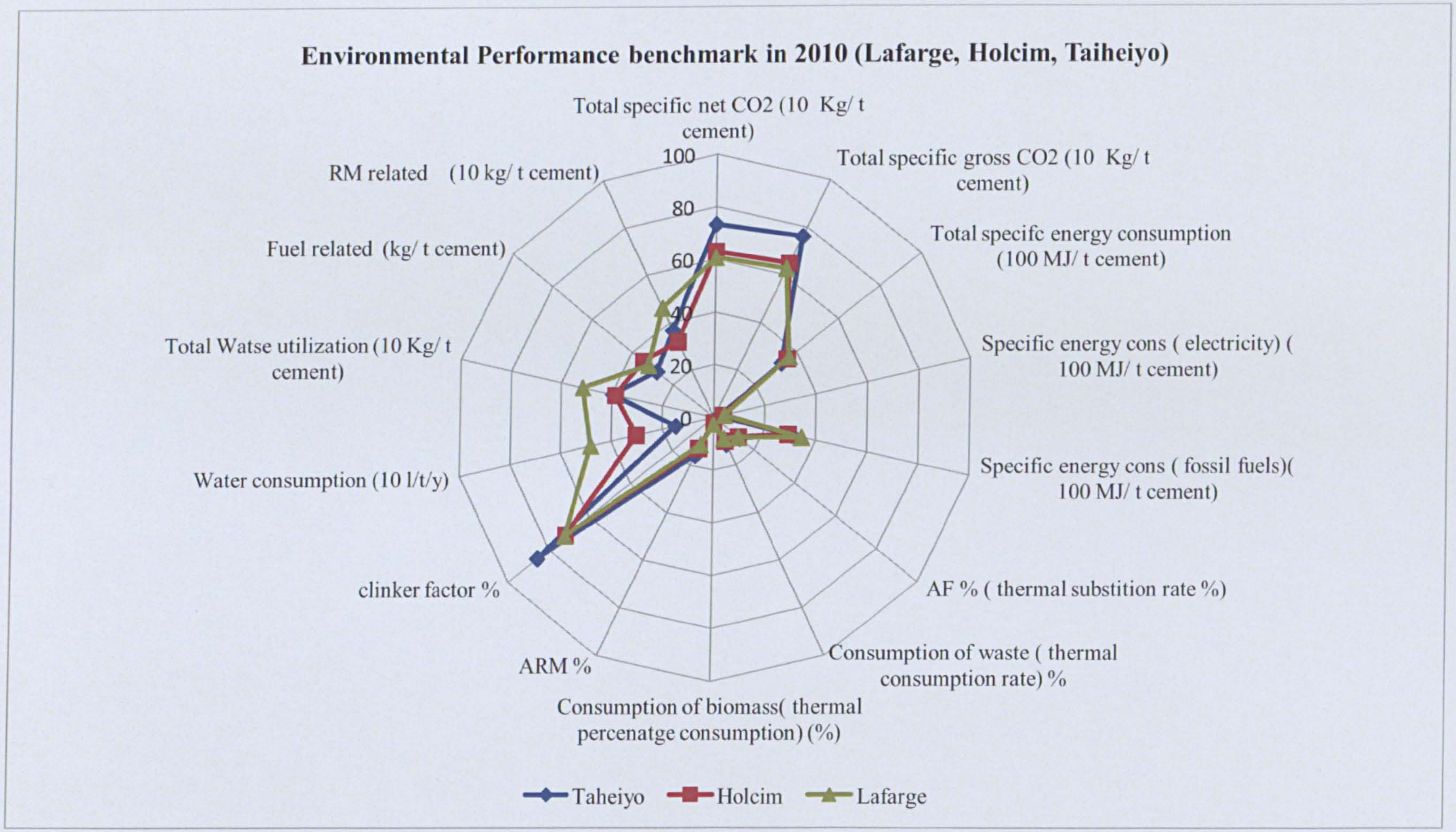


Figure 7.5 Environmental Performance benchmark in 2010 (Lafarge, Holcim, Taiheiyo) as found by this research

Table 7.4 best Performance Company as determined by using the scoring system

Environmental Performance Indicators	**Taiheiyo**			**Lafarge**			**Holcim**		
	2000	2007	2010	2000	2007	2010	2000	2007	2010
Total Specific Net CO_2 emissions Kg/tonne cement	3	3	3	1	2	1	2	1	2
Total Specific Gross CO_2 emissions Kg/tonne cement	3	3	3	1	1	1	2	2	2
Total Specific energy consumption MJ/tonne cement	1	1	1	2	3	3	3	2	2
Specific energy consumption (electricity MJ/tonne cement)	1	1	1	2	3	3	3	2	2
Specific energy consumption (fossil fuels MJ/tonne cement)	2	1	2	1	3	3	3	2	1
AF (Thermal energy substitution rate %)	2	2	1	3	3	3	1	1	2
Alternative fossil fuels consumption (percentage of the thermal consumption %)	1	2	1	3	3	3	2	1	2
Consumption of biomass (thermal percentage consumption %)	2	3	3	3	1	1	1	2	2
ARM %	3	1	1	1	2	3	2	3	2
Clinker factor %	3	3	3	2	2	2	1	1	1
Water consumption L/t /y	2	1	1	3	3	3	1	2	2
Total waste utilization Kg/tonne cement	1	1	3	2	2	1	3	3	2
Waste utilization Fuel related Kg/tonne cement	3	2	1	1	1	3	2	3	2
Waste utilization RM related Kg/tonne cement	1	1	2	2	3	3	3	2	1
Yearly Scoring average	**28**	**25**	**26**	**26**	**32**	**33**	**29**	**27**	**25**
Total Scoring over 2000–2010	**79**			**91**			**81**		

7.4 Results and discussion

According to a report prepared by the WWF in 2009 (Nicolas Müller 2008), around 55% of CO_2 released during the production of cement clinker is generated from the conversion of limestone ($CaCO_3$) into lime (CaO).

Around 40% of the emissions are released from the combustion process, which requires thermal energy heating at 1450°C. However, both emissions and fuel costs can be reduced by improving the energy efficiency measures.

Usage of biomass to replace carbon intensive fuels can substantially contribute to lowering the amount of CO_2 released from fuels.

That is what has been employed by Taiheiyo, as its rates of using biomass as AF were the highest among the three case studies, thus improving the efficiency of energy consumed at this company.

Biomass is one of the renewable energy sources that can replace conventional fossil fuels directly, either completely in small-scale applications or through blending with the corresponding fossil fuels in large-scale applications.

The biomass is considered CO_2 neutral. Thus its use as a substation for fossil fuels is promoted in order to reduce CO_2 emissions and consequently to reduce the impact on climate change (Antonia V. Herzog 2001).

However, additional reductions are possible through reducing consumption of the electricity generated by burning traditional fossil fuels.

This reduction in emissions derived from electricity could reach 10% of total emissions (Nicolas Müller 2008).

According to the scoring system used by the research, the best environmental performance was achieved by Taiheiyo Cement Corporation in Japan, with 2.7 MJ/MT clinker and 65 KWh/MT cement, although a gap in clinker ratio performance appeared between Taiheiyo and Lafarge, as well as between Taiheiyo and Holcim, as Taiheiyo's clinker ratio was the highest (blended cement proportions), and the amount of coal burned on site is also the highest.

These factors have resulted in the highest rates of CO_2 emissions released.

The thermal energy improvement for clinker-producing kilns was the best for Taiheiyo. In this regard, the rotary kilns mainly used by the company plants, in addition to create new technologies for Eco-cement production.

These include the AK system and wash ash processing, lowered the requirement for high thermal heating and consequently lowered the amount of energy needed to manufacture the final cement product.

Table 7.5 Taiheiyo figures for 2000 and 2010

Table 7.5 CO2 performance at Taiheiyo (2000-2010)	Total Energy consumption in 2000 (MJ/tonne cement)	Specific CO_2 emissions in 2000 (Kg/tonne cement)	Total Energy consumption 2010 (MJ/tonne cement)	Total CO_2 emissions in 2010 (Kg/tonne cement)
Cement manufacturing	2590	235	2870	293
On-site generator	816	74	222	37
Purchased electricity	231	7	195	
Subtotal	**3637**	**316**	**3287**	**330**
CO_2 from limestone		456		403
Total CO_2		772		733

But the percentage share of biomass in the fuel mix was not the biggest among those of the three companies.

Increasing the usage of biomass to replace conventional fuels at Lafarge and Holcim is considered one of the key means of reducing emissions of CO_2 and other GHGs (Nicolas Müller 2008).

A special mechanism has been used in the scoring system shown in Table 7.5, reflecting the level of sustainability performance for each individual indicator, category and group of indicators.

Collected data were translated from indicator value into sustainable measure. These measurements ranged from 1, the top performance level, to 3, the lowest performance level. In this case, the raw indicator values are formatted and compiled.

Hence what is represented is a score, standing for the formatted data, with the best performance scoring lowest.

Best performance company = the lowest total scoring level

The application of this system will help to minimize subjective measurement, since in this system a linear ranking scale to identify the level of each criterion has been used. The linear scale is based on the importance and impact of each indicator on the sustainability indicator among the other indicators in one group.

The aggregated result from this system was interpreted in Table 7.5, which assesses the level of each criterion that has been used and the total environmental impact for each case study.

In regard of energy consumption, ongoing changes and saving potential, the investigation and data analysis showed that Taiheiyo was the most efficient energy consumption. There have been significant improvements in Taiheiyo cement production operations over the last two decades.

More efficient equipment and energy-saving management practices have been adopted. Figure 7.6 illustrates the trends in specific energy consumption per tonne of cement produced from 1990 to 2010, including specific energy coming from fossil fuels, and electric power. Total energy consumed was 60.099 (1000 GJ) in 2010 compared to 101.457 (1000 GJ) in 1990.

However, the ratio of energy input from waste tyres, waste oil, and waste plastics used increased over the last five years. This boosted the proportion of materials recycled by Taiheiyo Cement within the total energy consumption.

The heat coming from fossil fuel burning per unit of production in 2010 was 2.870 MJ/tonne, with 0.417 MJ/tonne cement coming from electricity heating, decreasing from 3.036 MJ/tonne cement in 2005 from fossil fuels burning, but increasing above the level of electricity heating consumed in 2006, namely 0.334 MJ/tonne cement.

The replacement of conventional fossil fuels with waste and by-products increased in 2010 per unit of production, to reach 507 MJ/tonne cement from burning 371 Kg/tonne cement of waste and by-products in that year.

The grinding of raw materials is the principal consumer of electricity in the cement industry, 111.7 KWh/ tonne cement having been consumed for raw materials and cement grinding (Taiheiyo SDR 2010).

The total specific energy consumption decreased in 2010 by 8.4% from the 1990 level of 3591 MJ/tonne cement, to reach 3287 MJ/tonne cement in 2010. Figure 7.7 shows the environmental benefit of using AF in cement production at Taiheiyo and its role in protecting energy resources from depletion and reducing the consumption of natural energy.

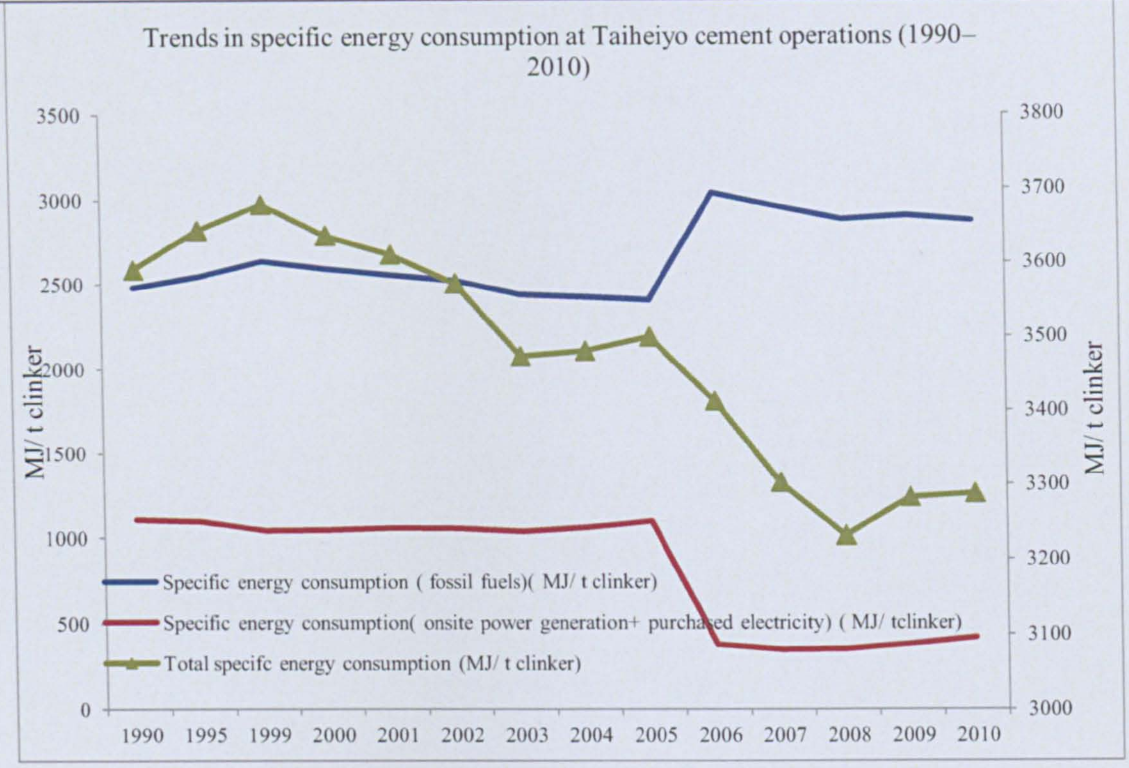


Figure 7.6 Total specific energy consumption including electricity consumption + fuels (data collected and analysed from Taiheiyo Sustainability Reports 1990-2010)

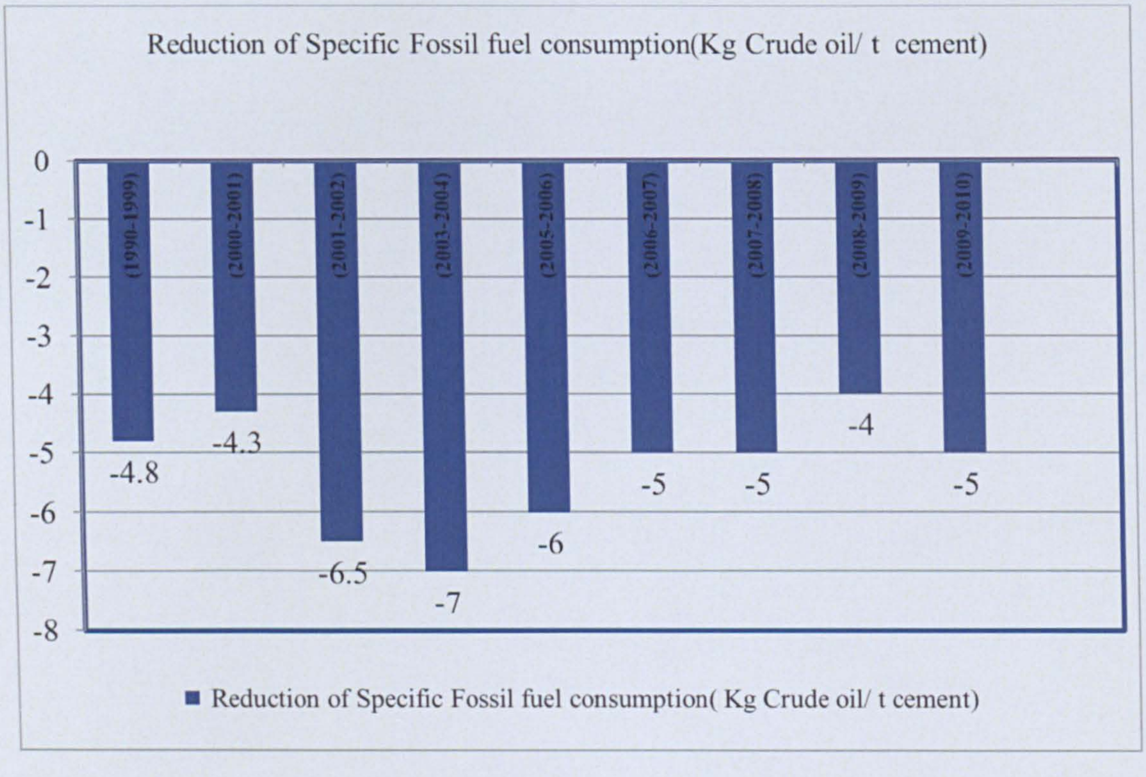


Figure 7.7 Trends in specific reductions of energy usage at Taiheiyo from 1990 to 2010.

7.5 Conclusion

The reduction of CO_2 emissions in cement production in the three identified case studies was achievable by using secondary raw materials that need to be ground or subsequently added to cement and by reducing the clinker factor.

This results in changing the reduction rates of CO_2 emissions in each of the comparable companies. The difference in the Gross CO_2 emissions was 13% in 2000 and 17% in 2007 between the best performance company, Taiheiyo, and Lafarge, which was the last company in CO_2 emissions released (as presented in Figure Radar 1,3).

Decreasing the clinker ratio in Lafarge cement production resulted in decreasing the percentage of raw materials along with the same percentage of coal burning and the CO_2 emissions linked to that reduction.

However, in future the possibility of maximal replacement of clinker with mineral additions, using different mineral additions and combinations, will yield certain improvements in cement as compared to OPC.

Waste usage as AF in cement production has various environmental benefits such as (Hendrik G. van Oss 2003):

- Limiting the usage of natural fossil fuels and the environmental impact of burning it.
- Playing a key role in reducing GHGs and utilizing waste materials which would otherwise be either dumped or incinerated, with consequent emissions and residues.

Substantially increasing energy recovery by using waste as AF in cement kilns to produce clinker. Additionally, the use of AF increases recovery of the non- combustible fraction of waste, as this inorganic part (slag or ash) will be used to replace the raw materials in cement production

In addition, utilizing renewable resources such as wind energy can produce the required power in place of burning traditional fuels such as coal for producing this power.

Chapter 8

Conclusions and Future Works

8.1 Conclusions

This research was carried out to develop and promote a new comprehensive procedure for assessing the level of sustainability in the context of cement production, with special reference to the environmental impact of CO_2 emissions released throughout the manufacturing process and the potential reduction in these emissions.

To complete the above task , it was essential to establish a comprehensive research methodology that would help to achieve both the general aim of this research, that is, to reduce the environmental impact of cement operations by producing cement with less CO_2 emissions, and the specific research objectives, namely, to improve energy efficiency and minimize its consumption, reduce the clinker factor, reduce the natural raw material consumed by cement production, and conserve natural resources and biodiversity.

Therefore, this research was conducted to assess the best environmental performance cement company and its potential for CO_2 emissions reduction in cement production. The investigation was carried out in response to the initiatives set by the Cement Sustainability Initiatives (CSI) project, which has operated under the World Business Council for Sustainable Development (WBCSD) since 1999. By using the Guidelines for Emissions Monitoring and Reporting in the Cement Industry, originally published in 2005, CSI members have begun to report annually on a set of agreed key performance indicators for emissions and to set their own emissions reduction targets. These guidelines provide CSI member companies, including Lafarge, Holcim, and Taiheiyo cement companies and the wider industry, with a common framework for monitoring and reporting on CO_2 and air emissions.

In this regard, the present research was based on identifying the world's best performance cement companies, in order to respond to key objectives related to:

- Measuring and assessing the sustainability level of each company, depending on the availability of data.
- Understanding the applications of previous sustainability assessment in the cement process, its limitations, and development trends.
- Identify key Environmental Performance Indicators related to the cement production process, taking into account social and economic performance.

- Measuring and assessing each cement company's improvement over the last two decades, from 1990 to 2010, in terms of the environmental impacts of cement production, in order to better understand its challenges in terms of the potential for reducing CO_2 emissions. This assessment was performed according to the previous EPI set by this research.
- Identifying the points of strength and weakness in the environmental performance of each of the chosen cement companies and comparing their performances over one decade, from 2000 to 2010.
- Employing a specific scoring system, based on the environmental performance indicators, to assess the best environmental performance company of the three cement companies studied for this research.
- Identifying specifically the levers for reducing CO_2 emissions throughout the manufacturing process, step by step.
- Formulating and generating general guidelines for the future of cement production within the scope of Sustainable Development (less CO_2, and more efficient energy consumption).

As a result, according to the scoring system employed, it was found that Taiheiyo Cement Company was the best of the three companies which were investigated in terms of their environmental performance impact. Taiheiyo was the most efficient energy consumer compared to Lafarge and Holcim; however, its specific net CO_2 emissions are still the highest as a consequence of burning fossil fuels more than Lafarge and Holcim. This point was discussed in greater detail in Chapter 7.

In terms of efficient energy consumption, sustainable energy will be promoted more effectively by the use of renewable energy resources such as biomass, wind, solar, and hydropower. One of the main reasons for the transition to a renewable energy-based system is the soaring price of conventional fuels such as oil and gas and the reductions in the cost of renewable resources.

The use of wind energy in Dunbar cement operations, as described in Chapter 4, confirms that future growth in the energy sector will take place primarily under the new regime of renewable energy, and to some extent natural gas-based systems, rather than from conventional oil and coal sources. The development and use of renewable energy sources can enhance diversity in energy supply markets, contribute to securing long-term sustainable energy supplies, help reduce local and global atmospheric emissions, and provide commercially attractive options to meet specific energy service needs, particularly in developing countries and rural areas, thus helping to create new employment opportunities there.

In terms of CO_2 released, it has been found that a key contribution to reduction of CO_2 emissions has been made by the use of alternative fuels and raw materials. Hence, the use of alternative materials for cement production has reduced global CO_2 emissions, reduced the need for quarrying and the environmental impacts of such activities, and still maintained the quality of the final product. The fundamental reasons why alternative fuels are suitable for use in cement kiln operations and contribute to CO_2 reduction are:

- Fossil-based fuels are being depleted; thus new fuel sources must be discovered.
- The energy component of alternative fuels enables them to replace the fossil fuels, as some of these alternative fuels are renewable, such as biomass (waste wood, rice husks, nutshells, animal meal, etc). In addition, their carbon content is less than that of coal or petcock, which emits high carbon into the atmosphere, resulting in burning and combustion. Holcim is advised to limit these in order to promote a better environment and avert the danger of global warming.
- The inorganic components such as ashes are integrated into clinker production, making them an effective substitute, with lower CO_2 emissions, for traditional solid fuels.

Furthermore, the reduction of CO_2 emissions in cement production is achievable by decreasing the clinker percentage in cement, decreasing the consumed percentage of raw materials, and improving the efficiency of fuels burnt throughout the process of cement manufacturing. The utilization of waste has offered a new approach for cement production and energy conservation and introduced a new and valuable product to the cement market, together with new recycling technologies which have saved valuable fossil fuels for future generations and reduced CO_2 emissions associated with fuels combustion and raw materials calcinations.

The recycling of industrial by-products technology has been well validated in global cement production in general and in the identified case studies in particular. The utilization of by-products such as rice-husk ash, silica fume, coal fly ash and slag, as discussed in the three case studies, has helped to reduce the CO_2 released, the CO_2 emissions having been cut by 16.5% -20%- 21% in 2010 compared to1990, at Taiheiyo, Holcim, and Lafarge, representing a total mitigation of 20 to 25 million tonnes of CO_2 equivalent per year. The clinker factor was improved for the three companies, Taiheiyo, Holcim, and Lafarge, from 92% in 1990 to 85%, 71%, and 72% in 2010. This development also improves the air quality, minimizes solid waste, and contributes to the sustainability of cement production. The reduction performance results from the intensive use of a combination of mitigation levers, including savings from the use of alternative fuels and raw materials and savings from reduced levels of clinker production.

When less energy is used, less energy is generated by power plants, thus reducing energy consumption and production. At Lafarge, the energy consumed in 2010 was 12% below 1990 levels. This in turn saved 8.75% of the CO_2 released to the air worldwide by Lafarge in 2010. At Holcim, the thermal substitution rate was 12% as against 5.4% in 1990, and at Taiheiyo, which was considered the most efficient company; the thermal substitution rate was around 13% in 2010, rising from 4.54% in 1990.

In sum, the assessment of the cement companies' performance showed that the sustainability of cement production was enhanced by: using/producing less clinker, consuming less water throughout the process of cement manufacture, approaching specific high quality process, and using minerals and additions that keep the chemical admixture of clinker but reduce the emissions released and conserve natural resources – since by replacing 10.56 of raw materials with slag and fly ash in cement works the CO_2 emission has been reduced by 5% as of 2010.

Therefore, cement production has offered unique advantages to the environment by saving 23% of natural resources (RM, fuels, water, and industrial by-products) through waste recovery technology and environmentally sustainable waste management, and to society by offering long-term, sound solutions for the treatment of waste produced by human activities. In addition, it has brought profit to the economy through the cost-effective replacement of natural resources consumed within the cement making process.

Furthermore, the three cement companies promoted a wide range of recycling activities, aimed at creating a recycling-based society. These activities contributed substantially to the reduction of natural resources consumption by waste recycling, as well as the reduction of social costs and environmental impact, which has decreased year-upon-year through the processing of waste.

Taiheiyo had the best performance by waste utilization indicators. The company's total waste utilization was 394.6 Kg per tonne of cement in 2010, including waste utilization related to fuel (27.9 Kg/tonne cement) and to raw materials (366.6 Kg/tonne cement). This utilization was increased by 48% compared to 2000 rates.

To summarize, the recycling of waste in cement operations had the following results:

- Reducing greenhouse gases by cutting down coal consumption and usage, so that CO_2 emissions declined, with change equal to 8985 1000 tonne of CO_2 below CO_2 emitted in 2000, by 29 Kg CO_2 emissions per tonne of cement produced. The percentage of the CO_2 emissions improvement equals 3, 8% saving on the 2000 level.

- Increasing the life of limited landfills by increasing the amount of waste used for cement production, from 199 Kg in 2000 to 249 Kg in 2010 of waste per tonne of produced cementitious materials.

- Recycling waste for raw materials as the subtotal of the alternative raw materials increased by 37% from 4220 (1000t) in 2000 to 5784 (1000t) in 2010; the proportion of total ARM within the total RM consumed in 2010 was 16%.

- Recovering energy from waste utilization, as the total specific energy consumption decreased by 9.62% in 2010 according to 2000 levels, going down from 3637 MJ/tonne clinker in 2000 to 3287 MJ/tonne clinker in 2010. However, most of this energy saving came from reducing the specific energy consumption (fossil fuels used on-site power + purchased electricity) by 630 MJ/tonne clinker, going down from 1047 MJ/tonne clinker in 2000 to 417 MJ/tonne clinker in 2010, rather than the specific heat consumption from fossil fuels: MJ/tonne clinker increased in 2010 by 280 MJ/tonne clinker above 2000 levels. In terms of Taiheiyo's recent environmental performance, the average fuel intensity required for clinker production showed an overall decline to 3 GJ/tonne clinker, the electricity use declined to 100 kWh/tonne cement, and the shares of coal, gas, and alternative fuels were 70%, 5%, and 25% by 2010. Furthermore, it was found in Chapter 6 that Japan was the most energy-efficient country. Hence, the energy requirement per tonne of clinker ranged between 3.3 GJ/tonne clinker in 1990 and 3 GJ/tonne clinker in 2005, these requirements in both the two years being the lowest worldwide.

- Decreasing the ratio of clinker to cement production, from 88.2% in 2000 to 85.7% in 2010.

8.2 Recommendations and further work

Upon completion of this research, a set of general recommendations and principles for sustainable cement production with less environmental impact to which attention should be paid have been drawn up as follows.

First of all, wind energy will out-perform any other renewable source for use in the production of cement, especially since they involve no removal of new fossil carbon from the earth. In addition, wind energy, with near-zero emissions, is one of the most competitive solution as it has been investigated by this study in Dunbar cement plant.

A large amount of CO_2 is emitted from generating power by burning fossil fuels as is the case for Teiheiyo, Japan. In the year 2000 the energy consumption rate at Taiheiyo was 3637 MJ/tonne cement, of which the consumption related to clinker production was 2590MJ/tonne. Fossil fuels used on site for power generation was 816MJ/ tonne cement. This rate of fossil fuels consumption makes Teiheiyo one of the highest CO_2 emitter.

Future study regarding truly sustainable cement production would thus address first and foremost the sourcing of energy (thermal as well as electricity). In view of the high temperatures required regarding thermal processing (around 1,700K is the kiln temperature for clinker production) an area of work could be to concentrate on solar thermal energy collection, further boosted by waste heat recovery. Furthermore, with regards to sourcing of sustainable electricity wind power has already been explored at Lafarge and Teiheiyo. In Japan there are also plans for very large-scale, Giga-Watt sized PV plants located on water surface within the Osaka Bay. Thus with a combination of wind and solar PV a big proportion of the electricity demand can be met in a sustainable fashion. Future work may explore the true extent of the latter technologies and the economics of such solutions.

Another of the areas of good practice that could potentially be explored by companies such as Teiheiyo would be waste heat recovery. The latter technology has been identified as being a good candidate for sustainable solution by the global cement industry in the developed and developing countries. Future research may thus be undertaken by identifying the extent to which waste heat recovery may be used by leading cement producers.

Yet another area of work could be to explore a reduction of the amount of natural raw materials, especially limestone that cement production requires and replace it with waste materials that have the same chemical structure but are carbon natural. Furthermore, procedures could be identified to reduce the clinker factor by using additives materials such as slag which is considered to offer a good promise for reducing clinker amount.

This study raised the complexity and difficulty of addressing sustainability, the necessity of lowering environmental impact while sustaining economic growth and social perspective. The intended result is to have a complete design process for cement manufacturing, showing the potential for reducing CO2 emissions step by step throughout the processes described in this work. Future work may thus incorporate such a holistic design approach.

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Appendices

Appendix1. Sources of ARM: ECRA Technology papers (2009). WBCSD & IEA Cement Technology

Clinker substitute	Source	Positive characteristic	Limiting Characteristic	Estimated annual production level	Availability
Ground blast furnace slag	Iron or steel production	Higher long term strength and improved chemical resistance	Lower early strength and higher electric power demand for grinding	200 million tonnes(2006)	Future Iron and steel production volumes are very difficult to predict
Fly ash	Fuel gases from coal-fired furnaces	Lower water demand, improved workability, higher long term strength, better durability(depending on application)	Lower early strength, availability may be reduced by change in fuel sources by the power sector	500 million tonnes(2006)	Future number and capacity of coal- fired power plants is very difficult to predict
Natural pozzolanas(e.g., volcanic ash) rice husk ash, silica fume	Volcanoes, some sedimentary rocks, other industries	Contributes to strength development, can demonstrate better workability, higher long term strength and improved chemical resistance	Most natural pozzolanas lead to reduced early strength, cement properties may vary significantly	300 million tonnes available (2003) but only 50% used	Availability depends on local situation. Many regions do not provide use of pozzolana for cement
Artificial pozzolanas(e.g. Calcined clay)	Specific manufacture	Similar to natural pozzolanas	Calcination requires extra thermal energy and so reduces positive CO_2 abatement effect	Unknown	Very limited availability due top economic constraints
Limestone	Quarries	Improved workability	Marinating strength may require additional power for grinding clinker	Unknown	Readily available

Appendix 2

Energy savings measures Emission reduction (Kg CO_2/tonne)

Improved refractoriness for clinker making in all kilns	10.3-15.5
Energy management and process control systems for clinker making in all kilns	21
Adjustable speed drive for kiln fan for clinker making in all kilns	3.97
Installation or upgrading of a pre-heater to a pre-heater pre-calciner Kiln for clinker making in rotary kilns	45.69
Conversion of long dry kilns to pre-heater/pre-calciner kilns for clinker making in rotary kilns	169.07
Dry process upgrade to multi-stage pre-heater kiln for clinker making in rotary kilns	141.44
Increasing number of pre-heater stages in rotary kilns	8.44
Conversion to reciprocating grate cooler for clinker making in rotary kilns	43.13
Kiln combustion system improvements for clinker making in rotary kilns	40.68
Indirect firing for clinker making in rotary kilns	0.39–0.57
Optimize heat recovery/upgrade clinker cooler for clinker making in rotary kilns	15.38
Low temperature heat recovery for power generation for clinker making in rotary kilns	19.18
Seal replacement for clinker making in rotary kilns	0.3
High temperature heat recovery for power generation for clinker making in rotary kilns	18.03
Efficient kiln drives for clinker making in rotary kilns	0.745
Replacing vertical shaft kilns with new suspension pre-heater/pre-calciner kilns for clinker making in vertical shaft kilns	62
Process control and management in grinding mills for finish grinding	2.63
Improved grinding media	3.34
High pressure (hydraulic) roller press for finish grinding	13.63
High efficiency classifiers for finish grinding	4.08
Efficient transport systems for raw materials preparation in dry process	2.61
Raw meal blending systems in dry process	1.37
Raw meal process control for vertical mills in dry process	0.94
High-efficiency classifiers in dry process	4.03
Slurry blending and homogenizing in wet process	0.15
Wash mills with closed circuit classifier in wet process	2.3
Roller mills for fuel preparation	0.25

Roadmap 2009 Carbon emissions reduction up to 2050

Appendix. 3 Waste Use*: Recycling and reuse materials found on superfund sites(either as ARM or AF in process of cement production)*

Waste Materials Used For Energy Recovery: (Wastes containing mainly organic contaminants)	**Wastes Materials Used as Raw materials: Wastes mainly containing inorganic contaminants**	**Other wastes**	**Examples of acceptable feed materials include the following sources**
1. Organic Liquids 2. Organic soils, sludges, and sediments 3. Petroleum- contaminated soils, sludges, and sediments. 4. Solvent-contaminated soils, sludges, and sediments 5. Propellants and explosives. 6. Rubber goods (e.g. tires and conveyor belts). 7. Polymers. 8. Wire stripping fluff, plastic fluff, and paint debris.	1. Metal-containing solutions 2. Metal- containing soils, sludges, and sediments 3. Slags. 4. Mine tailings. 5. Ashes (Bottom and Fly). 6. Spent Abrasive Blasting Media. 7. Foundry Sands 8. Batteries. 9. Mercury-containing materials	1. Municipal solid wastes, including non-leaded clear glass, white goods (e.g. refrigerators, washers, and dryers), automobiles, paper goods, and aluminium cans. 2. Pure metals, including iron, steel, and ferrous alloys, copper and copper alloys, nickel and nickel; alloys, and precious metals. 3. Mixed metal wastes with over 40 percent metal content. 4. Iron and steel blast furnace slags	**Alumina Sources** 1. Catalysts 2. Ceramics and refractories. 3. Coal ashes (fly and bottom). 4. Adsorbents for gases and vapours 5. Aluminium potliner waste **Calcium Sources** 1. Lime sludge **Iron Sources** 1. Foundry baghouse residuals 2. Iron mill scale **Silica Sources** 1. Abrasives 2. Ceramics 3. clay filters and sledges' 4. Foundry sand 5. Sand blast media 6. Water filtration media

Main Constituents of Portland Cement: (Tricalcuim Silicate, Dicalcuim Silicate, Tricalcuim Aluminate, Tetra calcium Aluminoferrite

Appendix.4 CO_2 emissions

4.1 (Direct CO_2 Emissions From Cement Production: Cement-Based Methodology) according to GHG Protocol Tool [Version: 2.0. June 2005].

The GHG Protocol offers two different tools for estimating GHG emissions from cement manufacture:

- US EPA tool: A cement-based tool requiring data only on annual cement production. Emissions are calculated using clinker: cement ratios and CaCO3: raw meal ratios. This tool is based on the U.S. EPA's Climate Wise program (1999).
- CSI tool: A clinker based tool suitable for when the amount of clinker consumed is known.

Table 4.1 Determine Direct Annual CO_2 Emissions from Cement production

A	**B**	**C**	**D**	**E**	**F**	**G**
Annual Cement Production (t/y)	Clinker to cement ratio (%)	Tonne of Raw Materials per tonne of clinker	$CaCO_3$ Equivalent Raw Materials (%)	CO_2 to $CaCO_3$ Ratio	CO_2 Factor (t CO_2/ t Clinker)	Annual CO_2 emissions from cement production (t CO_2/y)
	Default Value	**Default Value**	**Default Value**	**Constant** (0.44)	**B*C*D*E**	**A*F**

Table 4. 2 Default Value

Clinker to Cement Ratio (%) - 100% Portland output	95%
Clinker to Cement Ratio (%) - blended and/or masonry cement	75%
Tonne of Raw Material per Tonne of Clinker	1.54
CaCO3 Equivalent to Raw Material Ratio (%)	78%

$$\boxed{F1 = 0.5 * A}$$

F1= 95%*1.54*78%*0.44* A (Annual Portland Cement production)

$$\boxed{F2 = 0.373 * A}$$

(F2) Annual CO_2 from Blended or Masonry Cement (Clinker ration 75%)

F2= 75%*1.54*0.78*0.44* A (Annual Blended Cement production)

4.2 WBCSD Cement Sustainability Initiative: CO_2 Emissions Inventory [GHG Protocol,version2.0]

Default CO_2 Emissions Factors For Fuels			
Category	IPCC default (Kg CO_2/GJ)	CSI default (Kg CO_2/ GJ)	Comments
Fossil Fuels			
Coal+ anthracite+ Waste Coal	96		IPCC defaults are: 94.5 for coking coal and other bituminous coal. 96.0 for sub-bituminous coal. and 98.2 for anthracite
Petrol Coke		92.8	Based on measurements complied by CSI Task Force
(Ultra) heavy fuel	77.3		IPCC default for residual fuel oil
Diesel oil	74.0		
Natural gas	56.1		
Oil shale	107		
Lignite	101		
Gasoline	69.2		
Alternative Fossil Fuels			
Waste oil		74	Based on measurements complied by CSI Task Force
Tyres		85	Best estimate of CSI Task Force 1
Plastics		75	Best Estimate of CSI Task Force1
Solvents		74	Based on measurements complied by CSI Task Force 1
Impregnated saw dust		75	Best Estimate of CSI Task Force1
Mixed Industrial Waste		83	Best Estimate of CSI Task Force1
Other Fossil based wastes		80	Best Estimate of CSI Task Force1
Alternative Biomass Fuels			
Dried Sewage Sludge		110	IPCC default for solid biomass fuels
Wood, non impregnated saw dust		110	IPCC default for solid biomass fuels
Paper and carton		110	IPCC default for solid biomass fuels
Animal meal		89	Based on measurements complied by CSI Task Force 1
Animal bone meal		89	Best estimate of CSI Task Force1
Agriculture, organic, diaper waste, charcoal		110	IPCC default for solid biomass fuels
Other biomass		110	IPCC default for solid biomass fuels

IPCC defaults are from: Revised 1996 IPCC Guidelines for National Gas Inventories. Vol. III (Reference Manual), p.1.13

Appendix .5 Personal Contacts and communications with the cement companies

5.1 Contacts with Taiheiyo

May 7, 2009

Consulate-General of Japan in Edinburgh

2 Melville Crescent Edinburgh EH3 7HW
Tel: +44 (0)131 225 4777 - Fax: +44 (0)131 225 4828

To whom it may concern

This letter is to confirm that Mrs. Loubana El Atasi has been scheduled to visit Taiheiyo Cement Corporation between June 1 and June 2, 2009.

Mrs. Loubana El Atasi is visiting the company on an educational trip, for the purpose of researching information about the reduction of energy intensity for production of cement in Japan.

If you require more information about this trip, please contact Kimitaka Ando, General Affairs Department, Taiheiyo Cement Corporation (+81-3-5531-7335).

Yours sincerely,

吉田道夫

Michio Yoshida
General Manager
General Affairs Department
Taiheiyo Cement Corporation

熊 谷工場

360-8904

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Name = Mrs. Loubana ElAtasi

Affiliation = Edinburgh Napier University

Email = L.elatasi@napier.ac.uk

Telephone = +447828422174

Country = UK

Subject = Industrial visit to your cement works from a PhD student

Inquiry details = Dear Sir/ Madam,

I am Mrs. Loubana ElAtasi, a PhD student at Napier University, Edinburgh, UK.

I have a scholarship from The Syrian Government to look for sustainable solutions in Cement Industry in the Developed countries. I have done a survey of Syrian cement plants and would be happy to share that experience with your staff. My research project's title is 'Sustainable options for Cement Industry'. While searching for information I came across your landmark work on the reduction of energy intensity for production of cement in Japan. I am very keen to learn about your plant and its operation. In this respect I would like to have an industrial visit to Taiheiyo Cement Company plant in Japan.

I would be very grateful if you kindly grant me permission to visit your plant for a period of approximately one week. My visit can take place any time as soon as you schedule it.

Please note that the proposed visit will be fully supported by Edinburgh Napier University including medical insurance during my brief stay in Japan.

I remain most thankfully yours;

Mrs. Loubana ElAtasi (PhD student in Sustainable Construction)

School of the Built Environment

5.2 Contact with Holcim

Dear Loubana

Thank you for your e-mail, I hope you are fine as well and I am looking forward to meeting you on Tuesday morning, 11 August. Please find below the updated visiting schedule. It would be great if you could arrive at our premises (Hagenholzstrasse 85 in Zurich, please see the brochure I sent you on July 6) at 8.50 a.m. Please ask for me at the reception.

Tuesday, 11 August 2009: 09.00-10.00h, Zurich (office KID): Interview with David Kingma (Manager SD Coordination and Reporting): General questions on sustainable development 10.30-11.30h, Zurich (office KCL): Interview with Lorenz Koch (CO_2 Consultant): Questions on CO_2

((Transfer to Siggenthal plant, accompanied by Jerôme Laffely))

14.00-16.00h, Siggenthal: Plant visit and interview with Michel Monteil (Head of Environment, Health&Safety/Holcim Schweiz)

16.00-17.00h, Siggenthal: Interview with Jerôme Laffely (AFR Business Specialist): Questions on AFR/Life Cycle Assessment

Wednesday, 12 August 2009: 09.00-10.00, Zurich (meeting room 4): Interview with Luiz de Sousa (AFR Business Development/Senior Consultant Mediterranean & Africa): Questions on AFR/focus Middle East.

I hope you found a hotel in the city according to your wishes. Let me know if you have any further questions.

Best wishes

Seta

Seta Thakur

Holcim Group Support Ltd

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5.3 Holcim and Lafarge interview questions

Since, the research methodology is based on the Cement Sustainability Initiatives (Agenda for Action to the World Business Council for Sustainable Development); this interview will help in determining some facts regarding the development of cement industry worldwide in general and Holcim Cement Company in Particular. ***This is confidential and will be used for research purpose only; I really appreciate if you could spare a short time to answer this.***

1. What is your opinion with the Agenda for Actions provided by the WBCSD-explain why?
2. How did you become a member of the WBCSD, and when?
3. What changes and progress would you make since your membership in the WBCSD?
4. Can you Identify Holcim ways of increasing Capacity in the existing milling circuit, and its method to increase the efficiency in terms of energy usage?
5. How would you improve your cement manufacture process to mitigate its environmental impact?
6. What is Holcim tool to mitigate CO_2 emissions according to CO_2 Protocol Published by WBCSD?
7. How did Holcim apply the developed guidelines of the WBCSD for responsible use of fuel and raw materials?
8. How did Holcim apply the CO_2 Protocol measurement, monitoring and reporting of emissions?
9. What are Holcim emissions targets?
10. What are Holcim targets regarding the short term, medium term, and long term?
11. Did Holcim apply the ESIA (Environmental and Social Impact assessment-2006) guidelines process? And what are your tools to integrate these guidelines into decision- making processes?
12. Can you identify Holcim ways of increasing capacity into existing milling circuit, and its method to increase the efficiency in terms of energy usage?
13. Would you please specify what type of fuel you use(conventional and alternative)?
14. How much Direct greenhouse gas emissions from cement manufacturing

    - CO_2 from raw material Calcination
    - CO_2 from organic carbon in raw materials
    - CO_2 from conventional kiln fuels
    - CO_2 from alternative kiln fuels
    - CO_2 from non-kiln fuels
    - CO_2 from wastewater
    - Non-CO_2 greenhouse gases
15. What positive points you make in the last ten years to make the Cement industry a Sustainable Industry?
16. What are raw materials used and alternative raw materials used?
17. In the next ten years what are your directions to make it more sustainable?
18. How many people are working in the plant, and the company?
19. How much you pay for the workers salaries?
20. How much you pay for bills?
21. How much you consume of Gas, electricity, and fuels? How much you pay for each type of energy used?

22. How has your production been affected by the slow down economy and the financial crisis?
23. Could you please provide with more information on

However, Mr .David Kingman mentioned that Holcim Company has a branch in Middle East (Lebanon); could you please provide me with some information regarding its contribution to WBCSD initiatives in the Middle East regarding climate protection. fuel and raw materials, employee health safety, emissions reduction and the local impact?

I am highly appreciated your cooperation.

With my compliments,
Loubana

Appendix.6 Data sheets

6.1 Inputs of manufacturing process

1. Water	1990	1995	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	1990
Water consumption l/tonne cement/ year																
2. Waste utilization																
(fuels related) Kg/ tonne cement																
RM(RM related) Kg/ tonne cement																
Total waste utilization (kg/ tonne cement)																
3. Raw materials Inputs																
Natural raw materials inputs																
limestone (1000 tonne)																
Clay (1000 tonne)																
Silica (1000 tonne)																
Gypsum (1000 tonne)																
Other(1000 tonne)																
3.1. Trends of waste utilized as ARM																
Iron waste (1000 tonne)																
Fly/ coal ash (1000 tonne)																
By-products Gypsum (1000 tonne)																

Blast Furnace slag (1000 tonne)																
Other (1000 tonne)																
Subtotal of the ARM (1000 tonne)																
waste consumed as ARM Kg/ t cement																
ARM percentage (%)																
4. Subtotal of the ARM (1000 tonne)																
Total raw materials inputs (1000 tonne)																
Total RM+ ARM inputs																
5. Energy																
Energy Inputs																
Specific energy consumption (fossil fuels)(MJ/ tonne clinker)																
Specific energy consumption(onsite power generation+ purchased electricity) (MJ/ tonne clinker)																
Total specific energy consumption (MJ/ tonne clinker)																
5.1. Alternative Fuels																
Total alternative fuels rate (Percentage of thermal energy)																
Alternative fossil fuels consumption (percentage of the thermal consumption)																
Consumption of biomass(percentage of thermal																

consumption)																
6. Total inputs of cement process																
Alternative Raw materials ARM (%)																
Alternative Fuels AF (%)																
Total raw materials inputs (MJ/ tonne cement)																
Total energy inputs (Million tonne)																
7. cement production (1000 tonne)																
Clinker production (1000 tonne)																
Clinker factor (%)																
8.1 Industrial waste and By products (Kg/ tonne cement)																
Waste oil																
Recycled oil																
Used clay																
Used tires																
Blast furnace slag																
Non-ferrous slag																
Molding sand																
unburned Ash, soot, and Dust																
Coal Ash(including fly Ash)																

Sludge																
By-products Gypsum																
Construction waste																
waste plastic																
other(fuel related)																
Other raw material related)																
subtotal																
waste plastic																
8.2 Household Waste (Kg/ tonne cement)																
Municipal incinerator Ash																
water treatment plant sewage sludge and ash																
RDF(refused derived fuel)																
Other municipal waste																
Subtotal																
8.3 Total waste(Kg/ tonne cement)																
raw material related																
Fuel- related																

6.2 Outputs of CO_2

CO_2 intensity	1990	1995	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	1990	1995	1999	2000
Total specific net CO_2 (Kg/ t cement)																		
Total specific gross CO_2 (Kg/ t cement)																		
CO_2 of cement manufacture (Kg/ t clinker)																		
CO_2 from purchased electricity (Kg/ t clinker)																		
CO_2 on site generator (Kg/ t clinker)																		
Subtotal CO_2 from fossil fuels combustion (Kg/ tonne clinker)																		

6.3 Environmental Impact Assessment and the socioeconomic benefit evaluation (2000-2010)

Environmental Performance Indicators (EPI)	2000	2010	Changes
Total specific Net CO_2 emissions Kg/ t cement			
Reduction and improvement of the total specific Net CO_2 emissions %			
Improvement of the Clinker factor %			
Specific heat consumption from fossil fuels (MJ/ tonne clinker)			
Total specific energy consumption(MJ/ tonne clinker)			

6.4 Results of Environmental performance Assessment for (Taiheiyo, Holcim, Lafarge)

Environmental Assessment	1990	1995	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	1990	1995	1999	2000
Total specific net CO_2 (10 Kg/ tonne cement)																		
Clinker factor (%)																		
Specific energy consumption (fossil fuels)(100 MJ/ tonne clinker)																		
Specific energy cons (onsite power generation+ purchased electricity) (100 MJ/ tonne clinker)																		
Total specific energy consumption (100 MJ/ tonne clinker)																		
Total alternative fuels rate (Percentage of thermal energy %)																		
Subtotal of the Alternative Raw Materials ARM (100.000 tonne)																		
Total raw materials inputs (million tonne)																		
Water consumption l /tonne cement/ year																		
Water consumption m3/tonne cement/ year																		