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Environmental Impacts Associated with New Zealand Cement Manufacture

Roman Jaques

RESTRICTED

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Preface

This report details the environmental impacts associated with the extraction, transportation and manufacture of cement in New Zealand, using a methodology originating from a similar (but more detailed) Canadian study. It is the first in a series of reports examining the environmental impact of a variety of building materials, based on truncated life cycle analysis.

Acknowledgements

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Readership

This report is intended for environmental engineers, environmental technologists and researchers.

ENVIRONMENTAL IMPACTS ASSOCIATED WITH NEW ZEALAND CEMENT MANUFACTURE

BRANZ Study Report No. 68
Roman Jaques

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KEYWORDS

Cement; Environmental Impact; Ecological Impact; Cement Manufacture; Life Cycle Analysis; Life Cycle Assessment.

ABSTRACT

The environmental impacts associated with the manufacture of cement in New Zealand were investigated, using a similar Canadian study as a base document. Monitoring data for the 1995 year was collected from the three cement plants currently in production - Lee Cement Works near Nelson, Golden Bay near Whangarei and Milburn near Westport. Environmental impacts for the first three stages of cement manufacture - raw material extraction, transport to the plant, and the manufacturing procedure itself - were investigated. To create overall NZ energy and emission values, the values for each of the plants were proportionally weighted to take account of differing plant productions.

Only a small portion of the data set which the Canadian study obtained is available for New Zealand. Thus, comparisons between the two nations' cement operations were restricted, although increased monitoring is planned by some New Zealand plants in the near future. From the obtained information:

- in the extraction of the raw materials, the atmospheric emissions are higher in New Zealand for all the gases measured: CO₂, SO₂, NO_x, VOC's, CH₄ and CO.
- New Zealand's atmospheric emission figures for raw material transportation are similar to Canada's for all gases monitored, with the exception of NO_x. This is because of the reliance in some regions of Canada on (diesel-based) long-range rail freight, which results in the emission of high amounts of NO₂ compared to other modes of transport.
- New Zealand's total embodied energy intensity (extraction/transportation/production) for cement is 8% higher than Canada's. Only in the transportation component for New Zealand is the comparative figure lower.
- The level of other New Zealand cement-related environmental outputs, such as liquid effluents (from quarry water, stormwater run-off and the cement plant) and cement kiln dust, is unknown.

Contents

Page No.

1. INTRODUCTION	1
2. BACKGROUND	2
2.1 Life Cycle Analysis	2
2.2 Previous BRANZ Study	3
2.3 The Forintek Study	4
2.4 Research Approach.....	5
3. CONVENTIONS USED	5
3.1 System Boundary Limits	5
3.2 Data Categories and Quality	6
3.3 Standard Concepts	6
3.4 Terms and Definitions	7
4. THE CEMENT INDUSTRY	8
4.1 Overview of the Cement Manufacturing Process.....	8
4.1.1 Atmospheric emissions in manufacturing	9
4.1.2 Liquid effluents in manufacturing	10
4.1.3 Solid wastes generated in manufacturing	10
4.1.4 Industrial wastes utilised in manufacturing	11
4.1.5 Environmental emissions from other stages	11
4.2 The New Zealand Cement Industry	12
4.2.1 Individual plants	12
4.2.2 Recent changes to cement production	13
4.2.3 Greenhouse gas response.....	13
4.2.4 Site visit: Golden Bay Cement Works.....	14
5. PROCESS ANALYSIS - BY STAGE	17
5.1 Raw Materials Extraction	17
5.1.1 General notes on raw material extraction	17
5.1.2 Extraction results	19
5.1.3 Comparison with Forintek study	19
5.2 Raw Material Transportation.....	19
5.2.1 General notes on raw material transportation	19
5.2.2 Transportation results	20
5.2.3 Comparison with Forintek study	21

	Page No.
5.3 Cement Manufacturing	21
5.3.1 Manufacturing energy overview	21
5.3.2 Manufacturing results	22
5.3.3 Comparison with Forintek study	23
5.4 Embodied Energy - Summary	23
6. CONCLUSIONS	24
APPENDIX A: CEMENT UNIT FACTOR SUMMARIES	25
1. ENERGY USE	25
2. ATMOSPHERIC EMISSIONS	25
3. LIQUID EFFLUENTS.....	26
4. SOLID WASTE.....	27
5. PRODUCTION FIGURES	27
APPENDIX B: LETTER TO CEMENT PLANTS	28
REFERENCES	30

List of Figures

Page No.

Figure 1: Typical life cycle assessment matrix	2
Figure 2: The unit factor	8
Figure 3: The cement manufacturing process	12

List of Tables

Table 1: Atmospheric emissions due to raw material extraction (NZ)	19
Table 2: Atmospheric emissions due to raw material extraction (Canada)	19
Table 3: Energy consumption by mode of transport	20
Table 4: Emission factors for transportation, for various fuel types	20
Table 5: Atmospheric emissions due to raw material transportation (NZ)	21
Table 6: Atmospheric emissions due to raw material transportation (Canada)	21
Table 7: Embodied energy, by process (Milburn Cement Works only)	23
Table 8: Embodied energy, by process (Canada)	23
Table 9: Nationally weighted embodied energy figures (NZ)	23
Table 10: Nationally weighted embodied energy (Canada)	24
Table 11: Abbreviations used in tables	25
Table 12: Energy use by process stage	25
Table 13: Atmospheric emissions for raw material extraction	25
Table 14: Atmospheric emissions summary for transportation	26
Table 15: Atmospheric emissions summary for manufacturing	26
Table 16: Atmospheric emissions by stage of production	26
Table 17: Liquid effluents by type	26
Table 18: Cement kiln dust figures	27
Table 19: Cement types and acronyms	27
Table 20: Annual production figures for NZ cement plants	27

1. INTRODUCTION

The overall objective of this research was to obtain up-to-date information on the environmental impacts resulting from atmospheric emissions, liquid effluents and solid wastes associated with a common construction material used in the building industry, namely Portland cement. This work set out to:

- identify the major environmental impacts associated with the raw material extraction, processing and manufacturing of cement in New Zealand
- compare New Zealand's results to overseas data based on similar environmental impact studies, firstly to aid the development of a New Zealand database for materials, and secondly to compare the environmental impacts
- generate tabulated listings of environmental impacts for the extraction, transportation and manufacture of New Zealand cement.

This project supports a long-term goal of assisting in the development of a scientifically sound basis for determining the environmental impact of building materials. To achieve this aim, methods must be developed to allow both the building industry and the public to select building materials which result in the least environmental impact.

World-wide, tools to aid the analysis of environmental impact (both general and specific) are at a developmental stage. The recognised ideal approach for this type of environmental stress auditing is life cycle analysis, which considers a product from its inception to its termination. Unfortunately, the current implementation of life cycle analysis (LCA) has proved too complex (and therefore costly) for many applications, with its methodology being some way from final resolution. However, there is now a need to collect and compile data for those stages of LCA for which data is available for New Zealand. This will permit the identification of areas still requiring research and/or data collection.

This research report covers a simplified LCA study carried out for cement. It is the first of a series of studies to quantify the environmental impacts of common construction materials. The work reported here was funded by the Building Research Levy. Funding has been obtained from the Public Good Science Fund, administered by the Foundation for Research, Science and Technology to undertake a similar study on timber from site preparation to the mill gate in the 1997/1998 year. It is intended that additional building materials will be examined, depending on funding, in future years.

2. BACKGROUND

2.1 Life Cycle Analysis

The overall methodology used in this research report is based on life cycle analysis (LCA). Life cycle analysis is a means of identifying the complete environmental impacts caused by a product, and is usually considered as comprising four inter-related components (Canadian Standards Association, 1992). These four components are:

1. **Scoping**: the process of establishing goals and boundaries.
2. **Inventory**: a data-based process which quantifies inputs and outputs that occur over the life cycle of a product
3. **Impact Assessment**: a qualitative and quantitative process to assess the effects of the environmental burdens identified in the Inventory component.
4. **Improvement Analysis**: the evaluation process, where various ways in which the mitigation of environmental impacts associated with the inputs and outputs are investigated.

Life cycle assessment is the application of life cycle analysis to a specific product. The overall goal of using LCA is to reduce the environmental impact of a product. A typical matrix for life cycle assessment showing the various boundaries, for any material, is shown in Figure 1.

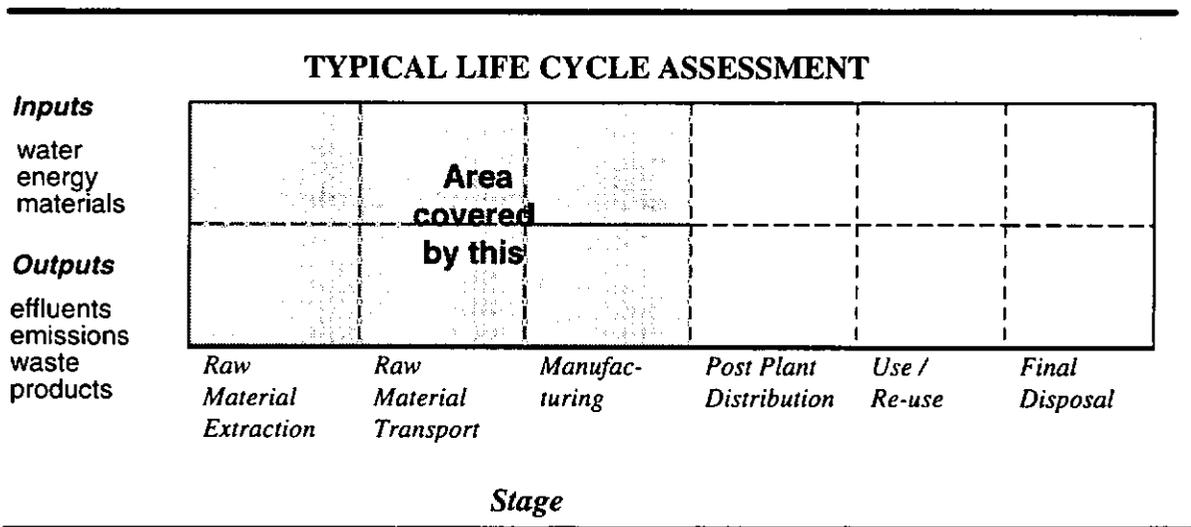


Figure 1: Typical life cycle assessment matrix

The environmental impact assessment stage has always been the biggest stumbling block in the whole LCA process. One of the major difficulties with this stage of analysis is the lack of a means of comparing different environmental impacts. For example, how does one compare the environmental impact (whether it be short or long term) of bio-diversity, say, against greenhouse gas emissions or groundwater pollution?

There have been various attempts to assign weighting factors reflecting the perceived or actual environmental risk of a particular pollutant. In many cases, the Delphi technique has been utilised to rank the various environmental risks, so that basic comparisons can be made between products. (The Delphi technique is a method of applying expert opinion to make consensus-based decisions). Thus, environmental risks, such as habitat destruction, global climate change or groundwater pollution may be ranked into, say, three groups, according to their impact - relatively high, medium or relatively low.

Other schemes (Ahbe et al, 1990, and Sage, 1993) have applied similar techniques to assign a single unitless value to resource use and emissions in order to calculate the total environmental impact of a product. These environmental impact values may be based on the carrying capacity of the natural environment, the actual human induced load, regional factors, the intensity and frequency of occurrence, or the cost of end-of-pipe mitigation measures. Thus, all enviro-impact values can be compared, because the assigned single values are unitless.

These evaluation methods and assessment techniques are still in their infancy. It has been shown (Baumann, 1996), for example, that a particular pollutant can be assigned a variety of weights or values. This variation can be attributed not only to the different effects considered, but also to the quality and accuracy of the data. Hertwich (Hertwich et al, 1996) found that, despite the common goal of the methods, there were considerable differences in the depth of analysis required in obtaining a value. He identified two problem areas:

- (1) the potential for recommending a product which actually has the highest impact (which negates the whole purpose of the process); and
- (2) the intolerance of imperfect data combined with the depth of information needed, resulting in extremely complex analysis for all but the simplest products.

Forintek explored the single value technique, in a comparison of the three major building materials - concrete, steel and timber (Forintek, 1993c). Four environmental impact dimensions were chosen - extensiveness, intensity, duration and significance. Each dimension was assigned a value, reflective of its environmental severity, given standard conditions. It was soon realised, however, that even the most tentative comparisons between the three material types and four environmental dimensions were fraught with difficulty, because of the inherent complexity and variability. It was suggested that further refinement and development is necessary before this technique can gain credibility, and therefore applicability.

Thus, for this report, only a simplified life cycle assessment was carried out.

2.2 Previous BRANZ Study

The "requirements typically specified to minimise the environmental impacts of primary processing of building materials" are considered to be (Bennett, 1994):

- *Specifying "typical requirements" is difficult, because of the relative youth of much environmental legislation. Many of the regulations and conditions are at a developmental stage, with few being formalised. [At present, "transitional*

provisions" are in force, which enable pre-1991 legislation to be applied until such time as regional rules are in place.]

- *Currently, the emphasis is on maintaining the status quo, and building upon existing knowledge.*

Before environmental impact requirements are prescribed by authorities, information on the current status of the environment must be available. It was found that, although some collection and collating of environmental data had been carried out by industries - in the form of emissions to air and water through consent applications - New Zealand is far behind the complex, prescriptive-based requirements and controls imposed on overseas industries. However, a first step has been achieved, in that industry is having to produce accurate concentration figures on a limited number of contaminants. Also, there are several central government initiatives which will aid environmental monitoring in the future, such as:

- *the Ministry for the Environment's plans to enhance environmental indicators which aim to address the current inconsistencies between different regions within the country*
- *the development of a monitoring framework for the Resource Management Act (which will aid New Zealand's "State of the Environment" report)*
- *the periodic cycle of OECD environmental reviews."*

To summarise, detailed data on emissions (to air, land or water) from the various manufacturing processes is not available in New Zealand. Even with the introduction of the Resource Management Act, it is not (yet) a mandatory requirement for New Zealand industry to collect detailed emission data of the depth required for this project.

For this research project, the focus is on what is "do-able" now. Overseas LCA work that has concentrated on building products will be used for comparative purposes to define terms and definitions, data collection procedures and boundary conditions.

2.3 The Forintek Study

The Forintek Canada Corporation project "*Building Materials in the Context of Sustainable Development*" (Forintek, 1993a; Forintek 1993b) - is a series of studies that has been used as a base document for this research. Forintek is approximately the Canadian equivalent of the New Zealand Forest Research Institute. Eight research organisations - from universities, private consulting firms, government agencies and private research firms - formed an alliance in 1991 to make available environmental data on common construction materials. The project was prompted by unsubstantiated claims promoting the environmental benefits of using timber alternatives in construction. This situation was exacerbated by the increase in timber prices that made steel and concrete more competitive than in the past. Forintek recognised the need to carry out life cycle analyses on timber and its competitors to achieve a fair comparison.

The Forintek study includes estimates for - raw material requirements, embodied energy, demand for water, solid wastes and a select number of atmospheric emissions.

The investigation can be grouped into four stages - extraction of raw materials, transport of raw materials, primary processing and transportation of the finished product.

The Forintek documents were chosen because of their transparency, objectivity, and because they are internationally acknowledged as one of the definitive works in LCA. For comparison purposes, conventions set down in the Forintek documents are applied to this research.

2.4 Research Approach

In early September 1996 letters were sent by BRANZ to the head chemist / resource manager of each New Zealand cement manufacturer, requesting input and output information on their respective plants. Specifically, the letter requested information on the emissions from manufacturing, specifics on cement kiln dust and liquid effluents, and annual throughput, all based on 1995 figures. It was stressed that information gained would be used in a fashion which was non-judgemental and non-comparative, in that no attempt would be made to rate or rank one building material against another. Since much of the requested information was of a confidential nature, weighted averages were to be used, to amalgamate data in the summaries. A copy of the letter is provided in Appendix B: Letter to Cement Plants.

It was decided to approach the cement plants for environmental information directly. Other data could be gained by sifting through large amounts of resource consent information at the local or territorial authority. However, this would be a tedious process, due to the way in which the data is collected. Alternatively, aggregated information could be accessed through publications in conference proceedings and specialist papers. Due to the nature of the data, time constraints, or confidentiality considerations, it was decided that co-operation from the cement plants was necessary for the inventory process.

3. CONVENTIONS USED

3.1 System Boundary Limits

Essentially, the "boundary serves to include all the essential information while excluding externalities which would not significantly increase the accuracy of the estimates" (Forintek, 1993b). The depth of analysis for this study is equivalent to a Level II analysis as determined by the International Federation of Institutes for Advanced Studies (IFIAS, 1974), which typically captures 90-95% of the full impacts. Thus, the boundary includes the acquisition, storage and transfer of raw materials, but does not include the construction of plant and vehicles, maintenance and administration and transportation of people.

The research project covered in this report focuses on cement rather than concrete (as was the case for the Forintek study), which is reflected in its different boundary. Therefore, the boundary limit for this project is "the acquisition (ie raw material extraction and transport to plant, storage, and production) of cement". It does not include concrete production or the transport of the finished cement to the various wholesale markets.

Accounting for ancillary materials - that is, material which is not used directly as a part of the product - is done in the following manner. If ancillary materials make up $\geq 2\%$ of inputs, then it should be accounted for. The exception to this is the inclusion of any material (no matter how small), which has extraordinary effects in its extraction/use/disposal.

3.2 Data Categories and Quality

The following standard data categories and quality (Forintek 1993a, b, c) are used in this report:

- data provided by industry should be designated as measured, derived, or estimated
- the most recent data should be used for unit factor calculations and the dates of the data should be noted
- the figures used should all be industry averages, with regional breakdowns where feasible
- for broad categories (such as particulates), some further characterisation should be provided
- ancillary materials must be accounted for if any single material makes up greater than or equal to 2% of inputs (by mass), or any group of ancillary materials which make up greater than or equal to 10% (by mass)
- estimations for transportation energy use include only the combustion energy and the empty back hauls
- all quantities to use SI units
- the units for energy, air emissions, liquid effluents and solid wastes for production will be normalised by unit of output (i.e. ensuring year-to-year comparability of figures by adjusting them for changes in production).

3.3 Standard Concepts

The following standard conventions (Forintek 1993a, b, c) are used in this report:

Non-Domestic Production: Imported materials will be factored into the domestic product based on the proportion of imports. Transportation factors for imports will be added based on the location, haulage distances and typical modes of transportation.

Process Feedstocks: The energy value of fossil hydrocarbons used as process feedstocks will be included in the gross energy figures for the product as if they were burnt as fuels.

Wastes and Recycling:

1. Wastes that are dumped must be environmentally accounted for.
2. The use of industrial waste from other industries (feedstock) is considered to be "free input" carrying no resource-use, energy or pollution impacts except for that from transport.
3. Post-consumer waste is assumed to have no energy or other environmental cost for its extraction or original processing, and only transportation energy and the environmental impact of its use in the new production process is accounted for.
4. Internal recycling is translated to improved efficiency (input/useful product) and reduced waste.
5. Waste energy reclaimed from within a plant will not be treated separately, but will appear as improved overall energy efficiency of the process.

Multiple Products: If several products are derived from one plant, with no way of separating the data:

1. if the differences in product processing are relatively minor, the energy and emissions will be apportioned on a mass or volume basis, or
2. if there are significant differences (i.e. $\geq 10\%$ of the gross figures for raw material, energy or emissions), the energy and emissions should be apportioned on the basis of the different steps required for each product.

3.4 Terms and Definitions

Ancillary Materials: that part of the material which is not used directly as a part of the final product

CKD: cement kiln dust

Gross System Inputs: the raw material and energy inputs from natural sources required to maintain the system in production

Gross System Outputs: the products and co-products, released by a system in production, including gaseous, liquid and solid wastes

Secondary Components: those which are manufactured, shipped and ready to install, and require some extra processing after the primary industry

Scrubbing: refers to the ability of limestone to absorb SO_2 during the calcination process

Solid Wastes: any solid by-product of any manufacturing stage which has no purpose in the process and which must be stored or landfilled. This includes particulates that have been collected from gas streams and solids and sludge from treated effluents.

TPM: total particulate matter

Unit Factor: the inputs (raw materials, energy, water), and the outputs (atmospheric emissions, air pollution, liquid effluents and solid waste) of an industry to a unit of its product. Note that the unit factor figures must be accompanied by definitions and clear boundaries, and that there is no absolute or correct unit factor of a material (refer Figure 2).

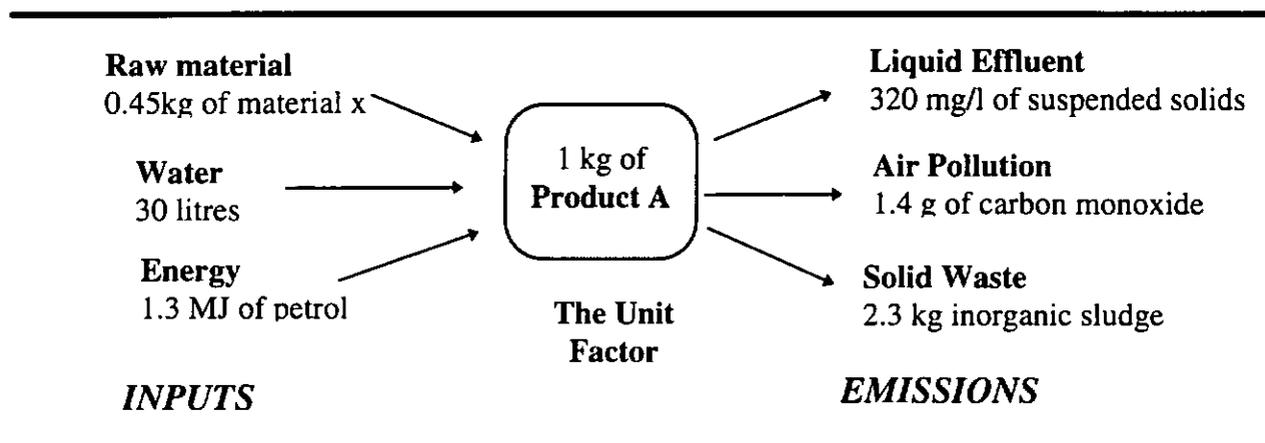


Figure 2: The unit factor

4. THE CEMENT INDUSTRY

4.1 Overview of the Cement Manufacturing Process

Most of this section is condensed from the documents "*The Manufacture of Portland Cement*", (Cement and Concrete Association, 1989), "*Raw Material Balances, Energy Profiles and Environmental Unit Factor Estimates for Cement and Structural Concrete Products*" (Forintek, 1993a), and personal communication with the chemists associated with New Zealand's cement plants.

Raw Materials

The basic raw materials used in the manufacture of Portland cement (termed 'cement' in this report) are limestone or chalk (which is rich in calcium), clay or marl (which are both rich in oxides of iron), alumina and silica plus alkalis - oxides of magnesium, sodium and potassium. Calcium and silicon are for strength, while the iron is used for its fluxing properties. At some plants, sand is also incorporated to give the correct starting composition.

Usually, about 20% clay and 80% limestone are used, but since the chemical composition of the raw materials varies with the location of mineral deposits, the proportions required for cement production may vary.

The raw materials are crushed at the quarry site then conveyed to the cement manufacturing plant, which is usually close to the quarry. They are then reduced to a

fine particle size so they can be thoroughly mixed. The crushed materials are blended and mixed to produce a finely ground powder of uniform chemical composition containing calcium carbonate, silica, aluminium and iron oxides and other compounds.

Processing

All plants burn coal to thermally process the cement raw materials to produce clinker, and use electricity primarily to grind the raw materials and clinker (Process Developments Ltd, 1995). Since 1996 some plants burn recycled oil also (see Section 4.1.4.). For the *wet process*, where the materials are ground and blended with water, the blending and mixing occurs during the grinding stage. For the *dry process*, where the materials are processed for firing without the addition of extra water, the blending process takes place separately from the grinding stage. The dry process requires less energy than the wet process.

The finely ground powder is passed through a kiln where chemical reactions take place. The powder undergoes its first change at about 800 °C, where the calcium carbonate in the mix decomposes to form calcium oxide (which remains in the mix), and carbon dioxide (which is driven off as a gas). This stage is termed the calcining stage. The mix progresses down the kiln, where it is subjected to temperatures of up to 1400 °C, and the mix becomes partially molten and the oxides of calcium, silica, alumina, and iron react to form calcium silicates, calcium aluminates and calcium aluminoferrites, the principal minerals of cement.

The resulting material consists of rough textured black pellets the size of marbles and is called clinker. The clinker is cooled, stored or sent directly to the mill for grinding with the addition of a small amount (3-5%) of gypsum. Gypsum is used to prevent instantaneous or flash setting occurring on the addition of water to cement. The finished product is then bagged or delivered in special bulk containers for sale. Around 700 000 to 800 000 tonnes of cement is consumed annually in New Zealand (Chisholm, 1997).

Cement plants are located close to the sources of primary ingredients - limestone and lime-rich clay.

Quality Control

Quality control in a cement plant is essential at every stage of production, and is governed by laboratory analysis. Even small variations in the raw materials may have a deleterious effect on the composition (and therefore performance) of the final product. Samples are collected from each stage, and tested chemically and physically at the laboratory. Cement produced in New Zealand complies with the specifications in NZS 3122 (SNZ, 1995).

4.1.1 Atmospheric emissions in manufacturing

The main atmospheric emissions from cement manufacturing are carbon dioxide (CO₂), oxides of nitrogen (NO_x), oxides of sulphur (SO_x) and particulates. The major source of emissions is the kiln operation, which releases NO_x, CO₂, water vapour and particulates. The amount of emissions is largely dependent on the fuel used to fire a cement kiln. The cement manufacturing process is unique among industrial processes in that it has lower comparative SO₂ emissions than other industries due to the scrubbing (absorbing) action of the raw materials.

Carbon Dioxide

About one tonne of CO₂ is generated for every tonne of cement manufactured. CO₂ is emitted from two sources: fuel CO₂ (from the burning of fuels) and calcination CO₂ (when calcium carbonate in limestone breaks down into calcium oxide). The total CO₂ emissions from the cement industry are fairly equally distributed between these two sources.

Sulphur Dioxide

About 200 - 1000 g of sulphur oxides are emitted per tonne of cement manufactured (net). SO_x are produced from the combustion of sulphur in fossil fuels, and the oxidation of sulphur compounds in the raw materials. Although sulphur oxides are produced in two forms (SO₂ and SO₃), nearly all the sulphur emitted is as SO₂. Around 90% of the SO₂ formed by the fuel combustion process is scrubbed (absorbed) by the CaO formed during the calcination process. All figures quoted account for scrubbing.

Nitrogen Oxides

Typically, about 2 - 6 kg of NO_x are formed per tonne of cement manufactured. Nitrogen oxides are formed during fuel combustion by oxidisation of the nitrogen in the combustion air and nitrogen compounds in the fuel. The three mechanisms of NO_x formation are: thermal (under fuel-lean conditions by high temperature reactions), prompt (under fuel-rich conditions) and fuel (formed when nitrogen in the fuel reacts to form hydrogen cyanide).

Particulate Emissions

About 0.3 - 0.9 kg of total particulate matter (TPM) is measured per tonne of cement manufactured. Particulates are generated in all of the cement production processes, but the largest amounts are generated in the kiln, clinker cooler and final grinding stages.

4.1.2 Liquid effluents in manufacturing

Very small amounts of water are used in the cement industry, with the dry process not using any water at all during its production. Water is used for peripheral activities, such as cleaning equipment and yards. Forintek (1993a, b, c) classifies water effluent into three types: cement plant (which is from rainwater washing away the cement dust); quarry water (from raw material extraction) and stormwater effluent (from sudden storms). Liquid effluents are considered to be the least detrimental of the environmental effects (ie both from a toxicity and quantitative perspective), compared to solid wastes and atmospheric emissions.

4.1.3 Solid wastes generated in manufacturing

During cement manufacturing, the main solid waste generated is cement kiln dust (CKD), produced during the tumbling of fine ground raw materials. CKD is swept out of the kiln by the hot combustion gases (Corish et al, 1995). Particulate emission control equipment is used to collect the dust, where it is often reintroduced into the kiln (depending on alkali content). Some CKD is used as fertiliser.

Solid wastes are also used in the cement industry, as replacements - also called fillers or extenders. For background material on this, see Section 4.2.2.

4.1.4 Industrial wastes utilised in manufacturing

Milburn Cement uses waste fuels - specifically oil, in the form of shipping oil (*heavy fuel oil - HFO*), and car sump oil (*lubrication oil*). This is an initiative of the "Oil Recovery Programme", a nationwide partnership between BP, Caltex, Shell, Castrol, Milburn Cement and the Ministry for the Environment. Milburn uses it in their high temperature kilns, as a fuel replacement for coal. Due to the high combustion temperatures, almost all of the contaminants are destroyed, with the remainder being incorporated into the clinker. By the year 2000, it is hoped that 95% of all collected used oil will be used this way. This programme started in June 1996 (Bond, 1996), and therefore is not considered in this study.

4.1.5 Environmental emissions from other stages

Raw material extraction

Solid wastes are generated from quarrying, in the form of overburden and topsoil removal. This is usually stockpiled for later reclamation, so is not considered waste. Although extraction of the raw materials results in much land disturbance, little environmental contamination usually results.

Atmospheric emissions are caused by fine (fugitive) dust emitted during the extraction process, and the usual emissions associated with the combustion of fossil fuels due to earthmoving machinery.

Raw material transportation

Only atmospheric emissions associated with the combustion of fossil fuels are present. All the four methods of transport (road, rail, shipping and electric conveyor belt) have been accounted for in this report.

The Cement Manufacturing Process

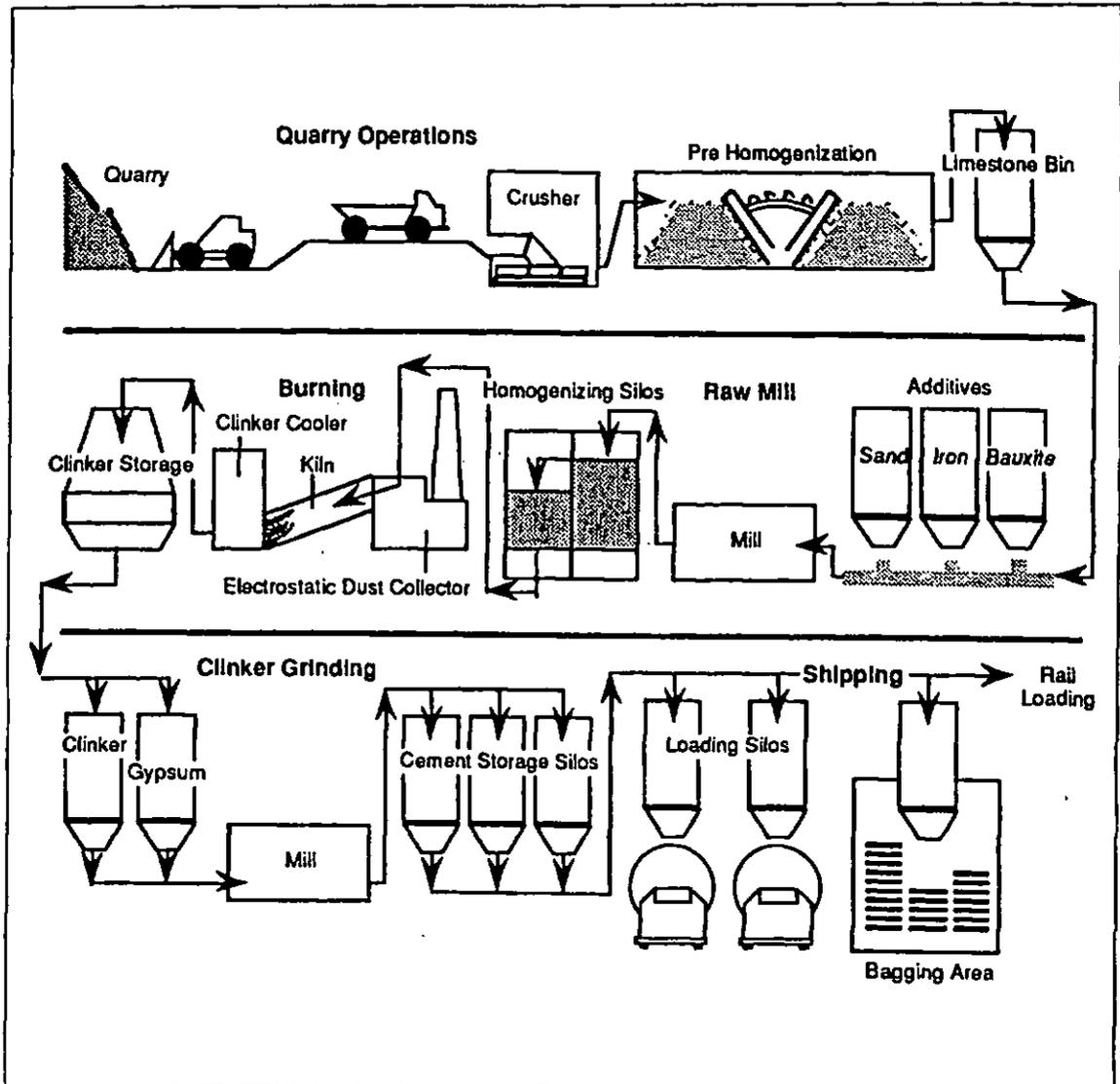


Figure 3: The cement manufacturing process

(Canadian Portland Cement Association, 1991)

4.2 The New Zealand Cement Industry

4.2.1 Individual plants

In 1996, three companies operated a total of five cement kilns at three plants, located in three areas. The following figures are based on the 1995 year, if not otherwise stated:

1. **Golden Bay Cement Ltd** at Portland near Whangarei has an annual cement production of 522,169 tonnes (approximately 55% of national production in 1993). This is achieved by using the more efficient dry process in its kiln. It includes a roller mill for raw material preparation, a short kiln with a four-stage preheater and three ball mills for cement grinding.

2. The Westport Plant in Cape Foulwind near Westport, operated by **Milburn Cement**, has an annual cement production of around 402 000 tonnes (approximately 43% of national production). This is achieved by using three wet process kilns. It has three wet ball mills for raw material preparation, three long wet kilns for clinker production and two ball mills for cement grinding.
3. **Lee Cement Works** is a comparatively small works which operates at Lee Valley near Nelson. It had a production of 20 321 tonnes in 1995 (which equates to about 2% of national production). This is achieved using a small modern dry process kiln. This plant opened on a continuous basis in late 1992 and is drastically improving its energy efficiency. Included in the plant is a roller mill for raw material preparation, a short rotary kiln with a four-stage preheater and precalcinator, and a ball mill for cement grinding (Process Developments, 1995).

4.2.2 Recent changes to cement production

Mineral fillers are now able to be added to cement, under NZS 3122 (SNZ, 1995). Mineral fillers include selected fly-ash, blast-furnace slag, limestone and other pozzolans. Up to 5% mineral fillers and up to 1% processing additions can be now added to what was previously known as OPC (ordinary Portland cement) and now renamed as general purpose cement (now Type GP). Milburn is using limestone additions, while Golden Bay uses fly-ash. NZS 3122 also caters for blended (now Type GB) cement which is defined as "containing Portland cement and a quantity greater than 5% of fly-ash or granulated iron blast-furnace slag, or both". Duracem, a product made by Milburn, comes into this category, and has a nominal slag content of 75%. A full list of the types and associated additives in cement available currently are given in Appendix A: Cement Unit Factor Summaries.

Slag and silica fume have to be imported, with fly-ash coming from the Huntly coal-fired power station. Silica fume is blended in at the concrete (rather than at the cement) plant. Using these materials results in a decrease in the amount of energy used (and therefore CO₂ production) per unit of cement. However, under the conventions imposed by this research, the environmental impacts of their transportation to the cement plant must be accounted for.

4.2.3 Greenhouse gas response

During cement production, CO₂ (a major greenhouse gas) is released from the process of calcination, the combustion of fossil fuels, and the generation of electricity. The CO₂ emissions from the New Zealand cement industry (using 1993 figures) are equal to approximately 0.52 tonnes per tonne of clinker from calcination, and 0.45 tonnes per tonne of clinker from fuel. It is estimated (Foreman, 1992) that the cement industry contributes around 3% of the nation's CO₂ emissions (and therefore less than 1% of the total greenhouse gases).

In May 1994, in response to the government's request for industries to voluntarily address New Zealand's greenhouse gas obligations, the cement industry formed the CIEMA - the Cement Industry Energy Management Association. This energy management partnership is between Golden Bay, Milburn, Lees Cement, the Maruia Society and the Energy Efficiency and Conservation Authority (EECA). The aims of the collaborative effort are to:

- share technical assistance in energy management
- benchmark the New Zealand industry against others, and
- monitor its performance and facilitate voluntary compliance with New Zealand's Framework Convention on Climate Change (FCCC) obligations.

CIEMA is targeting further energy efficiencies of 20% reduction by the end of the decade.

Currently in New Zealand around 5 GJ of energy is used per tonne of clinker (in the form of coal), which is significantly higher than the OECD and Western Europe average (Banks, 1994).

As part of the CIEMA deal, the New Zealand cement industry proposes to carry out the following activities (Process Developments Ltd, 1995):

- clinker cooler upgrades
- modifications to crusher screen and to raw meal feed system
- re-evaluation of co-generation
- slurry pump modifications
- upgrade to high efficiency fans
- use of slurry thinners.

Specific energy efficiency improvements planned in the near future (Process Developments Ltd, 1995), for each plant include:

Portland: a clinker cooler upgrade, the installation of variable speed drives and high efficiency fans, modifications to raw meal feed and raw mill, and the possibility of introducing co-generation using waste heat.

Milburn: improved dust return systems, the introduction of slurry thinners, upgrading to variable speed drives in exhaust gas fans, the rationalisation of slurry pumping, the installation of a crusher screen, and new PC-based controls for system operations.

Lee: the use of a precalciner, the introduction of cogeneration, reduction in the amount of false air, and the introduction of high efficiency motors.

4.2.4 Site visit: Golden Bay Cement Works

In May 1997, a site visit to Golden Bay Cement near Whangarei was made. The following information is current as at that date (rather than 1995 based) and was kindly provided by Paul Bonetti (Environmental Co-ordinator) and Danny Bourke (Resource Manager) from the Portland Works at Golden Bay Cement. Some information is taken from the flyer: "*Portland Cement Works: Summary of Assessment of Environmental Effects for Resource Management Consents*" (1993).

GENERAL

Golden Bay operates 24 hours a day and employs 145 staff (which includes quarry staff).

The introduction of the RMA has meant a major shift in the environmental management of the plant operations. All environmentally-related consents are now dealt with under the Resource Management Act 1991 (RMA). The costs of the set-up and changes to conform with the new effects-based document are estimated to be around \$500 000. Golden Bay Works requires consents for:

- discharge of stormwater
- discharges to ground and to water
- taking water from local land sources
- discharge of plant water (including cooling water)
- discharge of emissions to air
- for coastal works
 - authorising the existing reclamation
 - occupation of the reclamation
 - occupation of the existing wharf structures.

STORMWATER

Stormwater is collected in drains or runs over the land before being discharged into the harbour. It has been identified that stormwater is likely to pick up other material. However, no significant environmental effects are considered to arise from the stormwater discharges. The level of suspended sediments is being monitored and settling chambers for silt and oil have been built.

GROUNDWATER

Some of the rainwater filters through the site and discharges to the harbour as groundwater. Multiple wells were drilled on the site to determine the significance of this. In some of the wells levels of chromium were identified. This has been attributed to the extraction of chrome from kiln bricks. As a result, monitoring is being carried out on groundwater and sediments.

WATER SUPPLY

Water is used for three reasons on site - as a coolant in the cement process, for dust control and for farm supply on the adjacent site. The cement plant uses around 4000 cubic metres of water per day, for cooling purposes. There are three sources of water - a well, the Otaika Stream and drainage sumps on site. A water reclaim system has recently been put into operation, which has resulted in a dramatic reduction in the amount required by Golden Bay Cement. There are no significant adverse effects from the new reduced intake. Recently developed is a fish passage, to assist fish movement up the Otaika stream which was not possible beforehand. This was completed over the 1994 - 1996 period. The allowable limits of water take are being reduced as per resource consent conditions.

PLANT WATER DISCHARGE

Coolant water (which is contained within sealed pipework) is used for the air conditioners, compressors and the crusher. Total plant discharge into the harbour rarely exceeds 300 m³ per day in normal operating conditions. These discharges are being reduced. Monitoring of the water temperature at the two discharge outlets has been performed, showing that it is similar to the receiving tidal waters.

AIR EMISSIONS

Emissions arise from the manufacturing, handling and transporting processes. Assessments of effects conclude that adverse environmental effects can be mitigated and that ongoing monitoring of resource consent conditions demonstrates negligible environmental effects from the process. This is achieved through regular routine dust deposition monitoring, coupled with regular emission particulate matter monitoring and continuous opacity recording.

COASTAL WORKS

The Portland Works is permitted to occupy an area of foreshore and seabed for the purposes of operating and maintaining two existing wharfs. An assessment of the effects concluded that the coastal operations did not contribute to adverse environmental effects.

Other operations which have environmental implications are:

THE QUARRY

Environmental controls consist of: restrictions on overburden, handling and face heights. Dust is only a problem during summer, and is reduced by spraying using a spring on the quarry site. All quarry water is drained into one point, and naturally cleaned through a series of filters on site. Slopes are treated so that grass can grow back on them. Livestock is used to keep that grass down on the site adjacent to the quarry. Overburden has been used to extend a road at the back of the quarry, and is being considered by the District Council as a future landfill / cleanfill site.

LAND REMEDIATION

There have been significant developments in this area over the last few years. This includes extensive tree planting (over 100 000 trees) in the wetlands, the re-growth of mangroves, the development of birdwatching areas and general public access areas, and landscaping to some areas.

SOLID WASTES

Solid wastes include cement and kiln dust, which is controlled through dust collectors, by monitoring of stacks, and through a sweeping program. Larger wastes include the refractory (high temperature) bricks which line the kilns. These are dumped or used for hardfill. New kiln bricks are chrome-free.

ENERGY EFFICIENCIES - PAST, PRESENT AND PLANNED

Improvements in energy efficiencies in the Golden Bay plant, like all other cement plants, is an on-going feature. During 1994-1995, the clinker cooler system was upgraded, which has resulted in about a 10% increase in thermal efficiency. During 1995-1996, there was a switch from Huntly coal (around 23 MJ/kg) to Greymouth coal

(at around 29MJ/kg). This switch represents a significant decrease in the amount needed to be transported. Also during this period, the cement production was focused more on the larger cement mill, which is more energy efficient. In 1996, the use of cement replacements/fillers started in earnest, as a result of the introduction of the new standards. In 1997, opportunities for kiln firing and pre-heater tower improvements are being investigated. Other possible capital improvements include work on the kiln feed, but this is unlikely to happen before 1998.

5. PROCESS ANALYSIS - BY STAGE

This section will cover an inventory of the three stages examined as part of the truncated LCA study on cement - that is, the raw material extraction, transportation to plant and material processing. Each stage, and its associated assumptions, is outlined briefly, followed by a summary of relevant inputs and outputs. A comparison with the results from Forintek (1993a, b, c) is then provided.

5.1 Raw Materials Extraction

5.1.1 General notes on raw material extraction

- All quarrying carried out in NZ for cement raw material is open-cast.
- Estimates for the extraction energy relate only to the quarrying part of the operation and do not include primary crushing.
- It has been assumed that all energy use for drilling, trucking, front-end loaders and mechanical shovels is diesel powered.
- The limestone/clay/gypsum proportions are assumed to be 0.76/0.19/0.05 respectively (for all the quarries), for the weighted average calculations. These proportions are based on a nation-wide average and were used in an embodied energy analysis (Alcorn, 1996).

There are a variety of figures available for the extraction of raw materials. In Alcorn (1995), the embodied energy figures given are:

- 1.28 MJ/kg for calcium carbonate (limestone)
- 0.1 MJ/kg for clay and shale
- 0.75 MJ/kg for gypsum.

The limestone extraction figure is about 13 times the energy intensity of the clay and shale figures, which seems unjustifiably high, given that the process for each is very similar. Discussion with Alcorn (Alcorn, 1997) suggests that the limestone figure is based on the ERG report (American Institute of Architects, 1993), sourced from the USA, which is in turn based on 1985 figures. The non-limestone figures were established using various energy analysis techniques, based on national figures. This high limestone extraction figure seems unlikely when compared to the embodied energy figure for aggregate, which is 0.1 MJ/kg, based on Alcorn's own figure. Alcorn's general figure for mining and quarrying industries is 0.074 MJ/kg, which seems to be more reasonable, even though the mining portion is likely to be significantly more energy

intensive. (New Zealand's gypsum embodied energy figure is much higher than the respective Forintek figure, due to the longer transportation distance.)

Forintek (1993a, b, c) gives a generic figure for the extraction of all cement raw materials (using open-cast mining also) of only about 0.03 MJ/kg and states that this should be a reasonable assumption for limestone, clay, shale and gypsum. This aligns reasonably well with the mining and quarrying figures proposed by Alcorn.

Without sampling and averaging all the quarry sites in New Zealand to analyse their energy use, material waste and net production figures, it is impossible to say which of the figures quoted previously are most representative of the actual figure. It was decided to use the embodied energy value for the crushing of virgin rock from Alcorn's report, which equates to 0.074 MJ/kg (net). The current work that Victoria University of Wellington is carrying out for BRANZ will not be updating the quarrying figures, as it considers the figures to be satisfactory. The atmospheric emission figures are calculated (Table 1) based on the figures for diesel used in all the extraction machinery, at a typical quarry.

Quarrying activities generate large dust emissions. The estimate for the total particulate matter (TPM) was taken from the US Environmental Protection Authority (US EPA) paper, as figures were not available for NZ. It would seem that the level of dust emissions emitted from a particular material mined anywhere in the world, would be similar, as long as the mining technique was kept constant. However, field testing of this theory would need to be made to verify this with any degree of certainty. For this report, it was assumed that open-cast mining generates about 0.51 kg of particulate matter per tonne of finished cement. According to New Zealand experts (St George, 1997) particulate emission will vary between sites, and is dependent on the rock type, location of crushing facilities, extraction areas, topography, extraction rate and prevailing wind. No New Zealand particulate emission figures were known to be in existence at the time of writing.

In some plants in New Zealand, fugitive dusts from exposed yard areas and roadways are controlled by water sprays. Dusts from unprocessed and coarse crushed rock are considered minor due to the large particle size and moisture content.

The New Zealand figures in the following tables were generated from the input and output information provided by the three cement plants.

5.1.2 Extraction results

Atmospheric Emissions due to Raw Material Extraction (aggregated for all the cement plants nationally)

(g / tonne of finished cement)

NZ	CO ₂	SO ₂	NO _x	VOC	CH ₄	CO	TPM
Wtd Average	4 809	7.1	56.7	6.1	1.5	31.0	882

Table 1: Atmospheric emissions due to raw material extraction (NZ)

5.1.3 Comparison with Forintek study

Forintek (1993a, b, c) grouped the atmospheric emissions by region and city (rather than calculating a nationally weighted average). Production figures for each plant were unavailable, so an equal-weighted average figure was taken (amalgamating all the figures), for comparative purposes. These figures are given in Table 2.

(g / tonne of finished cement)

FORINTEK	CO ₂	SO ₂	NO _x	VOC	CH ₄	CO	TPM
Minimum	3123	4.5	35.7	3.9	1.0	19.6	834
Average	3141	4.5	35.9	3.9	1.0	19.7	839
Maximum	3155	4.5	36.0	3.9	1.0	19.8	843

Table 2: Atmospheric emissions due to raw material extraction (Canada)

As can be seen, all the atmospheric emissions are higher in NZ, for each of the gases examined. As noted in Section 5.1.1 General notes on raw material extraction, the atmospheric emission figures are based on the generic embodied energy value for mining and quarrying. It is suggested that the more energy-intensive figures may be due to economies of scale working against NZ, resulting in a less efficient extraction process. Note that in both the NZ and the Canadian cases, all the energy used for drilling, trucks, front-end loaders and mechanical shovels is in the form of diesel fuel, with all the mines used being of the open-cast variety.

5.2 Raw Material Transportation

5.2.1 General notes on raw material transportation

For each of the raw materials, the amount of energy expended in transportation to the cement plant was calculated. Backhauls were included in this estimate. A weighted average figure for the fuel types used was then calculated for each of the three cement plants. In the absence of New Zealand-specific data, all the energy consumption figures (apart from those for the conveyor belt) are taken directly from Forintek (1993a, b, c).

In one cement processing operation, an electric conveyor belt is used to transport raw materials to the processing plant. It was difficult to source any comparable energy consumption figure for this mode of transportation, so the assumption was made that it would have a similar consumption rate to electric rail transport. The electricity energy factor was sourced via TranzRail (Enouka, 1996).

Mode	Fuel	Energy Consumed (MJ/tonne - km)
Truck	Diesel - Road	1.18
Rail	Diesel - Rail	0.49
Ship	HFO - Marine	0.12
Conveyor Belt	Electricity	0.13

Table 3: Energy consumption by mode of transport

The following lists the transport modes and fuel types for each raw material, by cement plant.

GOLDEN BAY PLANT (WHANGAREI)

The *limestone* is mostly (75%) sourced from a nearby quarry on site. After being quarried and crushed, it is then transported 1.5 km to the plant by an electrically driven conveyor belt. The other 25% of the required limestone is transported from Hikurangi, some 24km north of Portland, by diesel truck. Due to the mineral composition of the limestone used, no *clay* or *shale* is needed. The *gypsum* is imported from either Australia (usually) or Mexico, depending on supplies. The *coal* is sourced from the West Coast (about 90%) using a barge, with Huntly supplies making up the rest. The Huntly coal is railed up - a distance of around 245 km.

LEE CEMENT PLANT (NELSON)

The *limestone* is sourced locally, and excavated and transported using diesel machinery, for the approximately 3 km to the plant. The *clay/marl* is also trucked in from the quarry, which is 3 km away. *Silica sand* (which makes up approximately 6-7% of the clinker), is sourced from Collingwood in Golden Bay, and trucked the 100 km east. The *gypsum* is trucked in from Christchurch, which is about 400km away. The *coal* is sourced from Reefton, and trucked the 190 km.

MILBURN PLANT (WESTPORT)

The *limestone* is crushed and blasted in Cape Foulwind, which is approximately 2 km away from the plant, transported by diesel truck. *Gypsum* is sourced from Australia. *Marl* is also quarried at the same site as the limestone, so travels around 2km. The *coal* is mined in the Westport area and transported by road, sourced from various mines. Estimated average transport distance by diesel truck is 20 km.

5.2.2 Transportation results

Energy Emission Factors for Various Transportation Types (kg/GJ)

FUEL	CO ₂	SO ₂	NO _x	VOC	CH ₄	CO
<i>Diesel Road</i>	70.7	0.102	0.807	0.0869	0.0217	0.443
<i>Diesel Rail</i>	70.7	0.102	1.4	0.07	0.0078	0.057
<i>Heavy Fuel Oil Marine</i>	74.0	0.45	0.2	0.36	0.04	0.0074

Table 4: Emission factors for transportation, for various fuel types

Table 4 is sourced from Forintek (Forintek, 1993a) and it agrees with New Zealand figures (Chivers, 1995). The Canadian figures were used for some of the pollutants because New Zealand data was unavailable.

Atmospheric Emissions Due to Raw Material Transportation
(aggregated for all the cement plants nationally)
(g / tonne of finished cement)

Emission/Transport	CO ₂	SO ₂	NO _x	VOC	CH ₄	CO
Wtd Av. Road	1 315	1.9	15	1.6	0.4	8.2
Wtd Av. Marine	3 430	21.2	9.4	17.0	1.9	0.3
Wtd Av	4 745	23.1	24.4	18.6	2.3	8.5

Table 5: Atmospheric emissions due to raw material transportation (NZ)

Table 5 lists the calculated atmospheric emissions due to raw material extraction in New Zealand, by mode of transport. These estimations include back-haul transportation, and a factor to account for process losses, as laid down by convention. The emissions caused by the operation of the electrical conveyor belt were discounted, as they were considered too small as to be consequential to the overall figures.

5.2.3 Comparison with Forintek study

Atmospheric Emissions Due to Raw Material Transportation
(g / tonne of finished cement)

FORINTEK	CO ₂	SO ₂	NO _x	VOC	CH ₄	CO
Wtd Av	7735.4	18.57	112.23	14.24	1.86	13.98

Table 6: Atmospheric emissions due to raw material transportation (Canada)

The comparative Forintek data is shown in Table 6. For most of the atmospheric emissions, the quantities emitted in New Zealand are very similar to the comparative figures in Canada. Without exception, all of the New Zealand weighted average figures fall within the Canadian regionally-based figures (not given here). The NO_x emission figure is the only one which is different by more than a factor of two. This may be attributed to the fact that in the Prairies Region (incorporating Calgary and Winnipeg) there is a heavy emphasis on rail (diesel-based) transport which has a very high NO_x concentration in comparison with the other fuel types.

5.3 Cement Manufacturing

5.3.1 Manufacturing energy overview

The cement manufacturing stage consists of the following process steps: primary crushing, secondary crushing, raw grinding, pyro-processing, and final grinding.

Only a limited amount of information on the environmental aspects of cement production is available in New Zealand. The Alcorn embodied energy study (Alcorn, 1996) gives a figure of 6.9 MJ/kg for cement. This is to IFIAS Level 4 analysis, using industry data. This figure is higher than the 4.78 MJ/kg figure in the Forintek document (Forintek, 1993b).

1993 Figures

Banks (1994) gives an average energy intensity, for the three cement works, of 5.18 MJ/kg cement, for the 1993 year. This is a weighted average, based on throughput for each works and assuming a 4% gypsum content. Over the next two years, improvements were made to the cement plants, reducing the energy intensity figures. Process Developments (1995) gives a weighted average of 5.33 MJ/kg of cement for 1993 Milburn, using 5% gypsum. This is a difference of under 3% - well within the accuracy of the embodied energy estimations and not considering the influence of the differing gypsum proportions.

In 1993, the Lee cement plant was in its first year of continuous operation, and so had several glitches - such as plant reliability - which needed to be attended to. Because of this, and the economies of scale, it was the least efficient cement plant operating nationally, even less efficient than Milburn's wet plant. However, with increased output and plant modifications, the embodied energy figures should improve significantly. The Golden Bay plant is by far the most energy efficient of the three plants, having around half the comparative energy requirements of the Lee plant, as well as being significantly more efficient than Milburn.

1995 Figures

The cement companies provided the following information:

1. **Milburn:** has changed its fuel sources, to incorporate used oil. Two types of oil are utilised: heavy fuel oil (around 70%) and sump oil (around 30%). Recycled oil is used and, as a "waste" from another industry, would not be included in the energy calculation - see Section 3.3. Although this could be incorporated into future estimations of atmospheric emissions etc, re-used oil was only introduced after the baseline year (ie 1995), so was not accounted for in this study.
2. **Lee Cement:** it was noted that coal consumption was unusually high due to major problems at a key mine, resulting in extended periods of unavailability of a critical coal.
3. **Golden Bay:** all figures were based on a July 1994 - June 1995 year (as was monitored), which has been considered to be satisfactory for research purposes. From an energy efficiency perspective, Golden Bay has the most efficient operation of all three plants due to economies of scale and the use of the dry production process.

Note that, for each of the cement plants, an embodied energy value (in MJ per kg cement produced) was calculated. As stated within the request letter (see Appendix B) these have been amalgamated for reasons of confidentiality.

5.3.2 Manufacturing results

The Forintek study relied on the Gardiner model (Forintek, 1993a) developed by Ontario Hydro, to generate estimates of the energy used in the various stages of cement manufacturing. New Zealand does not have a comparable model for the dry process operations. However, the Process Development Study (1995) gives specific energy

consumption data for the Milburn Works (the wet process), during the production of cement. The stages are divided up as follows:

Manufacturing Stage	Embodied Energy (MJ/t cement)	Percentage
Raw Material Prep	106	2
Pyro-processing	5982	95
Cement Grinding	172	3
Packaging + Dispatch	8	0.1
Ancillaries	10	0.1
Total	6277	100

Table 7: Embodied energy, by process (Milburn Cement Works only)

In Table 7, the electrical energy use was combined with coal use, to get a total energy use figure. Coal is used for thermal processing of the raw materials, while electricity is mainly used for grinding. Note that the bulk of the energy used was for the pyro-processing stage, accounting for 95% of the total energy for the entire process. Since the Milburn Cement Works is based on the wet process, which has different energy use characteristics and proportions compared to the dry process, these proportions have not been applied to the other cement works.

5.3.3 Comparison with Forintek study

Manufacturing Stage	Embodied Energy (MJ/t cement)	Percentage
Raw Material Prep	393	8.3
Pyro-processing	4162	87.6
Cement Grinding	194	4.1
Total	4749	100

Table 8: Embodied energy, by process (Canada)

A comparison between the two data sets is of marginal value, as the New Zealand figures are only based on one set of figures, which are not representative of the national figures. The large (24%) difference in the total energy requirements is to be expected, as all of the Canadian plants use the dry process, which is significantly more efficient than the one New Zealand wet plant.

5.4 Embodied Energy - Summary

Combining the previous figures on a nationally weighted basis gives:

Stage	Embodied Energy (MJ/kg cement)	Percentage
Raw Material Extraction	0.07	1
Raw Material Transportation	0.06	1
Manufacturing	5.19	98
Total	5.32	100

Table 9: Nationally weighted embodied energy figures (NZ)

Stage	Embodied Energy (MJ/kg cement)	Percentage
Raw Material Extraction	0.04	1
Raw Material Transportation	0.11	2
Manufacturing	4.75	97
Total	4.90	100

Table 10: Nationally weighted embodied energy (Canada)

The total embodied energy variations between the two nations are marginal, with less than a 10% difference. This is well within the accuracy of the embodied energy calculations, and therefore it may be said that there is no significant difference between the two totals. However, it can be seen that there is a difference between the transportation energy intensities (0.11 versus 0.06 MJ/kg cement). This difference is possibly reflective of the vast size differences between the two nations, and the resulting proximity between the cement plants and their respective mines.

The only raw material that has to be transported long distance for New Zealand cement production is gypsum, which is imported from Australia or Mexico. As only a small proportion of gypsum is used in the production of cement, it does not impact heavily on the energy intensity figure. Also, marine transport is nearly ten times as efficient as transport by diesel truck (which is the second most common mode of transport).

6. CONCLUSIONS

This report investigated cement-related environmental inputs and outputs during raw material extraction, transportation to plant and cement manufacture. All emission and energy figures were normalised (according to plant and associated quarry output), to be representative and to maintain confidentiality.

This report has shown that there is a lack of New Zealand information on environmental data, with a minimum amount of collection (compared to Canada) currently being done. This makes comparisons with the Canadian data difficult, if not impossible. The introduction of the Resource Management Act has meant that the required emission, effluent and solid waste information differs for each cement plant and associated quarry. Some plants are in the process of improving their range and depth of monitoring of environmental impacts.

For the atmospheric emissions examined, NZ's environmental imprint is heavier than that of Canada's, for the extraction, transportation and cement production. Comparisons for other emissions - such as liquid effluents and solid wastes - are impossible at this stage, because of an incomplete data set for some or all of the plants investigated.

Data was not available from most plants from raw material extraction, stormwater run-off or manufacturing. Solid waste, in the form of quarry overburden and cement kiln dust, was not monitored by most quarries and plants.

Further investigations in this area will either be heavily reliant on the use of overseas work as a base for assumptions, increased monitoring by individual plants (which was alluded to by some plants examined) or independent research monitoring.

APPENDIX A: CEMENT UNIT FACTOR SUMMARIES

Note that these tables all contain only a summary of the inputs and outputs from the three New Zealand cement plants, for confidentiality reasons. The tables are listed in the order:

1. Energy Use
2. Atmospheric Emissions
3. Liquid Effluents
4. Solid Waste
5. Production Figures.

Refer to Section 3. Conventions Used for the assumptions made when calculating emission values.

Table 11 explains the abbreviations used in the Appendix.

List of Abbreviations used in Tables	
<i>negl.</i>	= Negligible
<i>TPM</i>	= Total particulate matter
<i>unknown</i>	= Too many deficiencies in data set
<i>Wtd Av</i>	= Proportionally weighted, based on through-put for the year 1995

Table 11: Abbreviations used in tables

1. ENERGY USE

Energy Use in Cement Production By Process Stage
(GJ/tonne of finished cement)

Process Stage				
	Raw Material Extraction	Raw Material Transportation	Cement Manufacturing	Total
Wtd Av	0.07	0.06	5.2	5.33

Table 12: Energy use by process stage

2. ATMOSPHERIC EMISSIONS

A. Atmospheric Emissions Due to Raw Material Extraction
(g / tonne of finished cement)

	CO ₂	SO ₂	No _x	VOC	CH ₄	CO	TPM
Wtd Av	3 054	4.4	35.0	3.8	0.9	19.1	882

Table 13: Atmospheric emissions for raw material extraction

B. Atmospheric Emissions Due to Raw Material Transportation
(g / tonne of finished cement)

	CO ₂	SO ₂	NO _x	VOC	CH ₄	CO
Wtd Av	4 745	23.1	24.4	18.6	2.3	8.5

Table 14: Atmospheric emissions summary for transportation

C. Atmospheric Emissions Due to Cement Manufacturing
(kg emission / tonne of finished cement)

	CO ₂	SO ₂	NO _x	VOC	CH ₄	CO	TPM
Wtd Av	1 132	unknown	unknown	unknown	unknown	unknown	unknown

Table 15: Atmospheric emissions summary for manufacturing

D. Atmospheric Emissions by Stage
(g / tonne of finished cement)

Stage / Emission	CO ₂	SO ₂	NO _x	VOC	CH ₄	CO	TPM
Raw Material Extraction	3 054	4.4	35.0	3.8	0.9	19.1	882
Transport to site	4 745	23.1	24.4	18.6	2.3	8.5	unknown
Manufacturing	1 132 000	unknown	unknown	unknown	unknown	unknown	unknown
TOTAL	1 139 800	unknown	unknown	unknown	unknown	unknown	unknown

Table 16: Atmospheric emissions by stage of production

3. LIQUID EFFLUENTS

Very little liquid effluent monitoring is performed in New Zealand. Of the three stages at which liquid effluent could be monitored - during raw material extraction, stormwater run-off and the manufacturing process - only one plant monitored all of those stages. Even then, only five of the 14 possible effluent types that were commonly monitored in Canada were monitored here. Values for suspended solids, oil and grease, chromium, copper and zinc were provided. However, since this was sourced from only one plant, it was decided not to list them, as the figures may not be representative of national figures.

Liquid Effluents
(g/tonne of cement)

NZ	Raw Material Extraction	Stormwater Run-off	Manufacturing
Wtd Av	unknown	unknown	unknown

Table 17: Liquid effluents by type

4. SOLID WASTE

Cement Kiln Dust Discarded as Solid Waste

NZ	CKD as a percentage of Kiln feed	Total CKD (kg/t cement)	Waste CKD (kg/t cement)
Wtd Av	unknown	unknown	unknown

Table 18: Cement kiln dust figures

The solid waste emanating from the production of cement, in the form of CKD, for the three cement plants is either recycled back directly into the kiln (with any excess being sold as fertiliser) or not monitored at all.

5. PRODUCTION FIGURES

The following acronyms are used in the Appendix to describe the different cement types.

Cement Types and Acronyms

Acronym	Common Name	Additive
OPC:	Ordinary Portland Cement, now renamed GP	see below
RH or HE:	Rapid Hardening or High Early Strength	none (but ground finer)
Pacific:	Pacific	10% limestone
GB:	Blended	> 5% flyash or granulated iron blast furnace slag or both
PM:	Prise Mer	specialist formula for use with brackish water and in marine environments.
Duracem:	Duracem	75% slag
GP:	General Purpose	5% limestone

Table 19: Cement types and acronyms

Annual Production Figures, for the Year 1995
(tonnes / year)

Cement Plant (proportion of national production)					
<i>Golden Bay (55.3%)</i>		<i>Milburn (42.5%)</i>		<i>Lee (2.2%)</i>	
General	477 543	General	380 000	General	20 321
Rapid	34 429	Pacific	20 000		
PM	10 197	Blended	2 000		
TOTAL	522 169		402 000		20 321

Table 20: Annual production figures for NZ cement plants

Table 20, for 1995 production, shows the various types of specialist cement types by name and weight. As can be seen, most of the cement produced is of the standard "non-blended" product; for Milburn it equates to 95%, for Lee it equates to 100%, while for Golden Bay it equates to 98%. Thus, although there were multiple products from the plants, the consequence of the variations from the standard product were not considered in the input or output figures.

APPENDIX B: LETTER TO CEMENT PLANTS

The following letter was sent to cement plant head chemists or resource managers, requesting information.

(date)

(Name)

(Position)

(Postal Address)

Dear Sir

I am an environmental researcher from BRANZ looking at the ecological impact of common construction materials. BRANZ is an independent body representing the construction industry. You may be already familiar with some of our activities through the work of our cement and concrete section, which used to be part of the Cement and Concrete Association. We realise the growing importance of environmental issues of current concern to the industry. One of our long term goals is to compile an environmental impacts database for a variety of building materials, so that the industry can make informed decisions in the future.

The objective of this study is to gain estimates for all the inputs (eg raw material requirements, embodied energy, demand for water) and the outputs (eg solid and liquid wastes, and a select number of atmospheric emissions) for a given unit of material. All industry figures will be amalgamated to give a national industry average. Because of this amalgamation, confidentiality will be ensured even when there are only three industry manufacturers, as in the case of the cement industry.

The research is based on truncated life cycle analysis; that is, from resource extraction through to finished product. The study will be non-judgemental and non-comparative - thus it will not rate one building material against another, as we realise that the full assessment of environmental impacts of any product is an extremely complex area, and is yet without an effective methodology to support it. Ultimately the information will be used in conjunction with building design data, maintenance and durability information and economic considerations to get a better picture of a buildings environmental impact.

I recognise that there is much sensitive information contained both within the monitoring requirements imposed by resource consent data, and standard industrial emission monitoring programs. Nevertheless, I was hoping to access information on the following:

For the 1995 year (for the cement plant concerned)

1. What were the emissions due to manufacturing stage (in kg emission per tonne of cement produced or similar) for: SO₂ NO₂ VOC's CH₄ CO and particulate matter?

2. How much Cement Kiln Dust is reintroduced into the product? What happens to the residual dust that cannot be reintroduced? Is there any other source of solid waste in the manufacturing process?
3. Are the liquid effluents from the cement plant, storm water, and quarry water monitored? If so, what are they (in kg emission per tonne of cement produced or similar) for: Suspended Solids, Aluminium, Phenolics, Oil and Grease, Nitrates, Chlorides, Sulphates, Ammonia?
4. Cement production figures for the various types of cement.
5. CO₂ emissions associated with cement production: ie coal, power and limestone calcining.

I am aware that your cement plant is in a continual process of improvement, regarding use of resources - especially energy efficiency - which will effect the results. However, at present, I am more concerned with getting a "snapshot" of the year in question.

If you have any questions, please contact me at BRANZ. I have enclosed some background information on BRANZ. Thank you for your help.

Yours Sincerely

Roman Jaques
Building Technologist

REFERENCES

- Ahbe, S., Braunschweig, A. And Muller-Wenk, R. 1990. *"Methodik fur Oekobilanzen auf der Basis okologischer Optimierung"*. Schriftenreihe Umwelt Nr 133, BUWAL. Bern, Switzerland.
- Alcorn, A. June 1996. *"Embodied Energy Coefficients of Building Materials"*. Centre for Building Performance Research. Victoria University of Wellington. New Zealand.
- Alcorn, 1997. Personal communication.
- American Institute of Architects. April 1993. *"Environmental Resource Guide"*. Washington DC. USA.
- Annema, J, 1992. Pp 73-80. *"Life Cycle Assessment"*. Workshop Report. Leiden. The Netherlands. 2-3 December 1991. Society of Environmental Toxicology and Chemistry. Brussels.
- Banks, J. June 1994. *"Updating Cement Industry Energy Intensity Indicators to December 1993"*. New Zealand.
- Baumann, H. and Rydberg, T. 1994. *"A comparison of three methods for impact analysis and evaluation"*. *J. Cleaner Production*". Vol. 2 No. 1. Sweden.
- Bennett, A. F. 1994. Materials Manager, BRANZ. Personal communication.
- Bond, Jenny. December 1996. Assistant Environmental Analyst. Ministry for the Environment. Personal communication.
- Canadian Portland Cement Association. June 1991. *"The Cement Industries Contribution to Canada's Green Plan"*.
- Canadian Standards Association (CSA). August 1992. CSA-Z760. *"Environmental Life Cycle Assessment"*. Draft Version 5B. Canada.
- Cement and Concrete Association of New Zealand. *"The Manufacture of Portland Cement"*. November 1989. New Zealand.
- Chisholm, D. K. 1997. Senior Engineer, BRANZ. Personal communication.
- Chivers, M. 1995. *"Energy Greenhouse Gas Emissions 1990-1994"*. New Zealand Ministry of Commerce. New Zealand.
- Collins, C. February 1993. *"Transport Energy Management Policies: Potential in New Zealand"*. Energy Efficiency and Conservation Association. New Zealand.
- Corish, A. and Coleman, T. Sep/Oct 1995. *"Cement Kiln Dust"*. Concrete. United Kingdom.

- Enouka, M. TranzRail 1996. Transport engineer. Personal communication. New Zealand.
- Foreman, M. February 1992. "*Climate Warming: Government's Position on Carbon Dioxide Emissions and the Strategic Issues Facing Milburn*". New Zealand.
- Forintek. 1993a. "*Raw Material Balances, Energy Profiles and Environmental Unit Factor Estimates for Cement and Structural Concrete Products*". Part of the Building Materials in the Context of Sustainable Development series. Canada Centre for Mineral and Energy Technology and Radian Canada Inc. Canada.
- Forintek. 1993b. "*Phase II Summary Report - Unit Factor Estimates, Model Development and Related Studies*". Part of the Building Materials in the Context of Sustainable Development series. In association with Canada Centre for Mineral and Energy Technology. Canada.
- Forintek. 1993c. "*Ecological Carrying Capacity Effect of Building Materials Extraction*". Part of the Building Materials in the Context of Sustainable Development series. In association with Canada Centre for Mineral and Energy Technology. Canada.
- Hennessey, W. Whitney, R. Cairns, W. and Bedford, I. 199(3). Pp 88 - 98. "*Green House Gas Emissions from a Major Cement Producer*". Proceedings from the 4th Annual New Zealand Coal Conference. New Zealand.
- Hertwich, E., Pease, W., Koshland, C. 1996. Abstract from "*Evaluating the Environmental Impact of Products and Production Processes - A Comparison of Six Methods*". Submitted to The Journal of the Total Environment. United Kingdom.
- IFIAS (1974) Energy Analysis Workshop on Methodology and Convention. International Federation of Institutes for Advanced Study. Workshop Report No. 6. Stockholm. Sweden.
- McKinsey & Co, Inc. 1991. "*Integrated Substance Chain Management*" (and Appendix). Association of the Dutch Chemical Industry (VNCI). Leidschendam. The Netherlands.
- Portland Cement Works. 1993. "*Summary of Assessment of Environmental Effects for Resource Management Consents*". New Zealand.
- Process Developments Ltd. April 1995. "*Energy Consumption by the New Zealand Cement Industry*". Report No 94124038. New Zealand.
- Ryding, S. and Steen, B. Stockholm. 1991. "*The EPS System: A PC-based system for development and application of environmental priority strategies in product design - from cradle to grave*". IVL report B1022. Institutet for vatten och luftvardsforskning (Swedish Environmental Research Institute). Sweden.
- Sage, J. 1993. "*Industrielle Abfallvermeidung und deren Bewertung am Beispiel der Leiterplattenherstellung dbv-Verlag*". Technische Universitat Graz. Austria.
- St George, Dr. 1997. Mining Engineer. School of Engineering. Auckland University. Personal communication.

Standards New Zealand. 1995. "*Specification for Portland and Blended Cements*". NZS 3122 (1995).

Tasman District Council. 1993. Resource Consent Application for Lee Cement Ltd. Consent No. NN950366 (Notified). Discharge Permit. New Zealand.

West Coast Regional Council Resource Consents. 1994. File No 93/13 For Milburn (New Zealand) Ltd. Resource Consent No. 930011. New Zealand.



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HEAD OFFICE AND RESEARCH CENTRE

Moonshine Road, Judgeford
Postal Address - Private Bag 50908, Porirua
Telephone - (04) 235-7600, FAX - (04) 235-6070

REGIONAL ADVISORY OFFICES

AUCKLAND

Telephone - (09) 526 4880
FAX - (09) 526 4881
419 Church Street, Penrose
PO Box 112-069, Penrose

WELLINGTON

Telephone - (04) 235-7600
FAX - (04) 235-6070
Moonshine Road, Judgeford

CHRISTCHURCH

Telephone - (03) 366-3435
FAX (03) 366-8552
GRE Building
79-83 Hereford Street
PO Box 496