Date: December (2001)

BRANZ
THE RESOURCE CENTRE FOR BUILDING EXCELLENCE

STUDY REPORT

No. 106 (2001)

Environmental Impacts Associated with New Zealand Concrete Manufacture – Preliminary Study

Roman Jaques

The work reported here was jointly funded by the Foundation for Research, Science and Technology's Public Good Science Fund, and the Building Research Levy.

ISSN: 0113-3675

Acknowledgments

The co-operation of the following people involved in the cement and concrete industry, tertiary institutes and BRANZ is acknowledged. Bruce Campbell, Allied Concrete Ltd, Wellington; Peter Watson, Pre-Cast Components Wellington Ltd, Otaki; Paul Hancock, Ready-mixed Concrete, Hamilton; Harvet Tylor, Firth Industries, Christchurch; Rob Green, Higgins Concrete, Palmerston North; Brett Beatson, Stevensons and Sons, Auckland; Dorothy Walker, Cement and Concrete Association of New Zealand; Danny Bourke, Golden Bay Cement; Sheralyn Hume, Milburn; as well as Nigel Isaacs, Derek Chisholm and Eddie Bruce, all of BRANZ. A special thanks to Andrew Alcorn, Centre for Building Performance Research, Victoria University of Wellington, for his replies to my many embodied energy enquiries.

The work was funded by the Public Good Science Fund, administered by the Foundation for Research, Science and Technology, and the Building Research Levy. It is intended that additional construction materials will be examined in future years.

Readership

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

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REFERENCE

Jaques, R. 2001. "*Environmental Impacts Associated with New Zealand Concrete Manufacture – Preliminary Study*". BRANZ Study Report SR 106. Judgeford.

KEYWORDS

Concrete, Environmental Impacts, Environmental Auditing, Life Cycle Inventory, Life Cycle Analysis.

ABSTRACT

A life cycle inventory study of concrete in New Zealand was conducted, using methodologies from a Canadian study. In all, seven concrete products – 17.5 MPa, 30 MPa, and 40 MPa ready-mix concrete, double tee and hollow core precast units, and concrete block and mortar – were investigated. The inventory boundary specifically examined the first three stages of each product's life - raw material extraction, transportation to manufacturing plant, and production – commonly known as cradle-to-the-gate analysis. Four areas were investigated – energy use, atmospheric emissions, water usage and solid wastes. As part of the study, a major review of the 1998 BRANZ cement report was performed.

Information was sourced through published material, industry contacts and the results of an industry-specific questionnaire. Production figures from a modest sample of ready-mix and precast operators were based on those most recently available, mainly from 1999. As a consequence of the limited survey, this data should only be considered to be indicative and preliminary.

A comparison with a Canadian life cycle study was conducted. This comparison was restricted mainly due to the slightly differing products being examined. This research concluded that concrete production in New Zealand (circa 1999) and Canada (circa 1992) have similar energy requirements, cause similar amounts of atmospheric emissions and produce similar amounts of liquid wastes.

1. INTRODUCTION

This research provides environmental data about atmospheric emissions, energy use, water and solid wastes associated with a major building material. The object of this research was to *"quantify the major life cycle inventory impacts associated with the processing and manufacturing of concrete products"*. The seven concrete products investigated are:

- 17.5 MPa, 30 MPa, 40 MPa ready-mix concrete
- precast 'double tee' beams
- precast hollow core flooring
- masonry block
- cement mortar.

Estimates of raw materials, energy and water use inputs per unit of concrete product were developed based on industry data, energy studies and other published material. The bulk of the industry data came from a small sample of ready-mix and precast plants – therefore should be only considered indicative. Without doing a much larger in-depth study (i.e. greater than 30 ready-mix and precast plants for statistical reasons, Pollard, 1999), it is impossible to tell if these figures are nationally representative. However, this preliminary study does provide the framework and foundation on which more detailed studies can be built, as well as giving an indication of current practices.

A simplified life cycle inventory (LCI) for concrete is performed, starting from raw material extraction, through to the end product's manufacture. Worldwide, nenvironmental profile tools are still in the development stages. The recognised ideal approach for this type of environmental profiling is life cycle analysis (LCA), which considers a product from its inception through to its termination. The current implementation of life cycle analysis has proved too complex and too costly for many applications, with its methodology being some way from final resolution. However, there is a need now to collect and compile data for those stages of LCA for which data is available in New Zealand. This will permit the identification of areas still requiring research and/or data collection.

This preliminary study supports a long-term goal to assist the development of a scientifically sound basis for determining the environmental impact of building materials. Details from this type of study can be expanded to allow both the building industry and the consumer to select building materials that result in reduced environmental impact.

This is the fourth report in a series of BRANZ studies constructing environmental profiles of common building materials - the previous three were about cement (Jaques, 1998), sawn timber (Gifford et al, 1998) and steel (Jaques, 2002). This report should be seen as a companion to the cement LCI study. However, it does contain significant cement-related updates (for the manufacturing stage only), and should be read with this in mind.

2. BACKGROUND

2.1 Life Cycle Analysis

The methodology used for this research report is based on life cycle analysis (LCA), which is a means of identifying the complete environmental impacts caused by a product. The overall goal of using LCA is to reduce the environmental impact of a product or component, by providing as complete a picture as possible of the inputs and outputs resulting from the manufacture and use of a product. LCA usually comprises four inter-related components. The four components are: 'scoping', 'inventory', 'impact assessment', and 'improvement analysis'. This study of concrete manufacture focuses almost entirely on the inventory stage.

Life cycle inventory (LCI) is a sub-process of LCA that quantifies the inputs and outputs that occur over the life cycle of a product. The inputs and outputs quantified include: raw materials, solid wastes, emissions to the atmosphere, and liquid effluents. In this study the inventory will target the first three stages of the life cycle:

1. raw material extraction/collection
2. raw material transportation
3. product manufacture.

In short, this is a 'from-cradle-to-gate' study.

2.2 The Forintek Study

The Forintek Canada Corporation project *"Building Materials in the Context of Sustainable Development"* has been used as a basis for this research (Forintek, 1993 and Forintek, 1993a). In 1991, eight North American research organisations formed an alliance to make available environmental data on common construction materials. The project was prompted by unsubstantiated claims promoting the environmental benefits of using timber (over other) alternatives in construction. It was recognised there was a need to carry out objective, scientifically based analyses of timber and its competitors, to achieve a fair comparison based on the life cycle approach.

The Forintek study includes estimates for raw material requirements, embodied energy, demand for water, solid wastes and a select number of atmospheric emissions. The study can be grouped into four stages; extraction of raw materials, transport of raw materials, primary and secondary processing and transportation of the finished product.

The Forintek study is recognised as one of the definitive works in LCA, and was chosen as a model due to its transparency and objectivity. For comparison purposes, the conventions set down in the Forintek document were applied to this research.

2.3 Research Approach and Methodology

As part of LCA, a 'unit factor' (i.e. a specific weight of material which has defined boundaries) is used for inter-product comparisons. Ideally, in a study like this, the unit factor would be found by examining all inputs (materials, energy, water) and outputs (emissions to air, land and water) for each plant in detail. Because of the large number of New Zealand concrete plants (approximately 170 ready-mix plants and 38 precast) and the lack of readily-available plant-specific information, plant-by-plant analysis could not be carried out. Instead, seven ready-mix plants and three precast plants were investigated – together accounting for the production of over a half million cubic metres of concrete per year, equating to approximately 15% of 1999's annual (total) production. Unit factors for the various concrete products were based on many assumptions, the chief one being that the plants investigated were representative of all those operating in New Zealand. Other assumptions that were made included:

- The mix design ratios (i.e. product formulation) for all the concrete products examined were consistent for all of New Zealand.
- The manufacturing technique for each of the products is the same for all of New Zealand, as is the energy required and fuel types used.
- Atmospheric emissions, liquid effluents and solid wastes related to the various concrete types are nationally constant.
- Transportation distances for the acquisition of the raw materials (including those as part of the manufacture of cement) are dependent on the grade of concrete product.
- All reinforcing steel for the precast products is sourced from Pacific Steel, which is the sole manufacturer and supplier of reinforcing bars in New Zealand to precast concrete plants. A weighted average transportation distance is based on the national concentration of precast operations.
- The year investigated (1999) is representative, being a good indicator of present operations.

Mix design ratios, manufacturing techniques and atmospheric emissions may vary between concrete plants. Variations occur due to the slightly different raw materials, capital equipment and fuel types being used at any one time. However, for the purposes of this study, it is necessary to formulate an 'industry average' which is fairly representative of the current concrete operations.

Transportation modes and distances for raw materials can vary considerably between concrete plants. For this preliminary study, a weighted average distance figure was calculated, and proportioned according to the mode of transport and the size of the operation. This was thought to be the most representative method for accounting for fuel use and the resulting atmospheric emissions.

1999 was chosen as the year to study the environmental impacts of the manufacture of precast concrete for the following two reasons: it is by default, the most reflective of technological efficiencies, being the most recent year for which information is available; and it provides a 'snapshot' of what current practices entail. This gives a researcher a base on which to develop and expand this data in the future. For a preliminary study such as this, it is important to have a structural base on which further investigation can be carried out.

In the development of LCI for concrete, each of the process stages – raw material extraction, transportation to concrete plant (whether precast or ready-mix), and final manufacture – was analysed separately. LCI figures were weighted or normalised according to output. The procedure for carrying this out was as follows:

1. Find the (weighted) average raw material requirements (and therefore the mix proportions) for each of the concrete types.

2. Estimate the transportation distances (and modes) between quarries and plants for each component.
3. Find the (weighted) average manufacturing energy use and associated fuel requirements.
4. Find the (weighted) average atmospheric emissions, by process stage, taking account of process-related emissions in addition to emissions from fuel combustion.
5. Estimate the (weighted) average solid waste produced by process stage.

2.4 Concrete Products Investigated

Life cycle inventory studies were conducted on the following concrete products:

- 17.5 MPa, 30 MPa, and 40 MPa ready-mixed concrete
- precast 'double tee' beams
- precast hollow core extruded flooring
- masonry block
- cement mortar.

These products were chosen because they cover a range of common, non-specialist concrete products that require a minimum of specific design. (The products' specific design may vary, however, according to its application). The products are also similar to those chosen by Forintek.

3. THE NEW ZEALAND CONCRETE INDUSTRY

This section gives a quick overview of the New Zealand concrete industry, focusing on the areas of manufacture, the ready-mix industry structure and environmental-related initiatives carried out over the last decade.

3.1 Concrete Manufacturing

Concrete is essentially composed of cement, aggregate and water. The water combines chemically with the cement to form a matrix with the aggregate, which strengthens with time. To be a suitable construction material, the resulting concrete must possess adequate strength, wear resistance, watertightness and volume stability. These properties depend on the completeness of the chemical reaction known as hydration.

Chemical and mineral additives can be added to the concrete mixing process to adjust its fresh and hardened properties. Developments in chemical and mineral additives have occurred as a result of two driving forces: speed of construction and the durability of concrete (Mehta, 1999).

The 17.5 MPa, 30 MPa, and 40 MPa ready-mixed concrete may be either centrally mixed or transit (truck) mixed. Central mixing is where all mixing is done in a single large mixer at the plant the mixed concrete is then offloaded into the concrete truck, ready for transportation to the site. Transit mixing is where the majority of the mixing is carried out in the transporting truck's bowl, to be ready by the time the destination is reached. Concrete for precast products ('double tee' beams and precast hollow core extruded flooring) can either be mixed on site or ready-mix concrete from an adjacent ready-mix plant can be used. Concrete for masonry blocks is mixed at the place of manufacturing, while cement mortar is always mixed on site.

This preliminary BRANZ study focuses on central-mixed plants (although truck mix plants differ very slightly) that are generally thought to have superior wastewater facilities due to their "*permanency and greater land availability*" (Forintek, 1993). This choice was determined by the project's boundary of 'cradle-to-factory gate' analysis, which is less well defined for transit mixing.

The 'typical' workings of a central-mixed ready-mix plant are shown in Figure 1, although it should be recognised that all ready-mix plants differ slightly in their set up (Campbell, 1999). The process for the transit mixer plants is only marginally different.

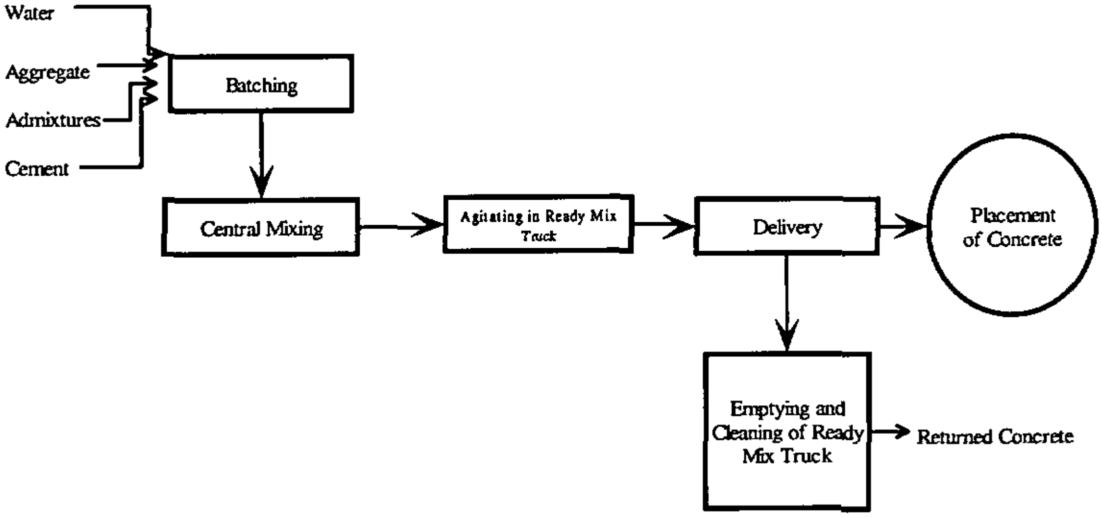

Figure 1: Typical central-mix, ready-mix concrete production in New Zealand.

3.2 Industry Structure

New Zealand has about 170 ready-mix concrete plants and about 38 precast plants (Chisholm, 1999). Ninety percent of the ready-mix plants are represented by three companies who are linked to major cement manufacturers. The remaining 10% are independent companies. The ready-mix plants and precast plants are widely dispersed through the country. The annual total production of concrete in New Zealand is about 3.36 million cubic metres, (2.25 million cubic metres for ready-mix alone) for the year ending March 1999 (New Zealand Concrete, 2000).

Cement sales (and therefore by implication, concrete sales) by market sector can be grouped into six categories, according to end use – 'products / precast', 'pipe', 'merchant', 'masonry', 'ready-mix' and 'other'. As an indication of the significance of these market sectors in terms of relative size, 'ready-mix' makes up for about two thirds of the sector, with 'merchant' and 'masonry' together making up for about a quarter (Thomas, 2000).

3.3 Environmental Initiatives

3.3.1 Energy efficiencies

There have been a variety of efforts to reduce energy use in the manufacture of concrete. Since 1994, most of these efficiencies have targeted the cement part of concrete manufacture (being the most energy intensive of all the raw materials) and include (CIEMA, 1999):

- raw material changes and optimisation of the energy balance in the kilns to improve thermal efficiency
- equipment modifications and upgrades
- increased use of used oil (which has a lower CO_2 emission factor as well as less preparation energy required) as a supplementary fuel
- improvements in slurry production techniques, pumping technology and storage systems.

In 1995 general-purpose cement (type GP) was introduced as 'standard' cement replacing the previous ordinary portland cement (OPC). In type GP cement, blending of up to 5% mineral fillers (e.g. limestone) and up to 1% processing additives (i.e. fly-ash) is allowed and this has reduced the embodied energy of finished cement. Also blended cements containing > 25% supplementary cementitious materials were introduced for specialist applications.

3.3.2 Reduction in water use for concrete plants

It is recognised that concrete plant operations are large consumers of water (Campbell, 1999), with truck mix-operations (unless they use a recycling method) using more than central-mixed plants (Forintek, 1993). Water is used for batching, truck washing, mixer washing and general yard purposes. Overseas, it is estimated that between 500 and 1500 litres of water are used to wash down an average plant and yard at the end of each day, plus 100 litres to wash out each mixer (Feger, 1990).

Concrete plants are making ever-increasing use of recycled water. Recycled water can be sourced from mixer washout water (slurry water), waste water from general operations, and stormwater. In some cases, up to 100% of this water is recycled. BRANZ has performed some preliminary studies evaluating concrete made from recycled slurry water. The use of slurry water in concrete is becoming increasingly attractive due to the increasing cost of disposing of waste concrete and the decreasing availability of landfills (Park and Chisholm, 1996).

3.3.3 Use of waste concrete

Waste concrete from mixing plants accounts for a small percentage of all the concrete made – industry estimates range from less than 0.5% to up to 3% by volume. It is generated as a result of off-specification products, overestimation of concrete required, and washout from operations. Assuming 1.5% wastage, this translates into 50,400 cubic metres of concrete for the 1999 year for New Zealand.

Waste concrete can be used for a variety of applications, depending on the plant. Most of the ready-mix plants interviewed had facilities to mould their excess concrete into 1 cubic metre blocks. These blocks are used for riparian protection or defining bin areas in landfills and transfer stations. Alternatively, the excess is used for infill material on construction sites.

3.3.4 Recycled aggregate work

In some urban sectors in New Zealand, the supply of virgin aggregate used for concrete is becoming scarce (Park, 1998). As a result, it has become viable to set up concrete crushing operations in these regions. These crushing plants are able to accept, process, and on-sell demolition concrete and rubble. Demolition concrete is separated from its reinforcing steel and crushed to specific recycled aggregate sizes. There are many benefits of using recycled aggregate – reduction in waste material being dumped, concrete is estimated to be 26% by weight of the waste stream in the Auckland Region (Patterson, 1997), the replacement of a scarce resource, and reduced tipping fees for contractors. At present, only non-premium roading products and base courses are being made from the demolition aggregate. However, this is likely to change, with the aggregates being used for low-strength applications, following overseas trends (Buck 1977, Sautner, 1999, and Morel, 1994).

BRANZ has performed some preliminary investigations into the properties of concrete made from recycled demolition rubble. These preliminary investigations found that using recycled demolition rubble as coarse aggregate is a viable proposition. However, concrete made from recycled aggregate would be more applicable to lower-strength applications - which accounts for a considerable amount of the total use - such as driveways, footpaths and house foundations etc, where its particular characteristics (lower strength and higher shrinkage) can be easily accommodated (Park, 1998).

3.3.5 Recycled polystyrene

There has been some research conducted into the use of lightweight concrete, as a way of reducing expanded polystyrene waste. Lightweight concrete is usually defined as having a density of 1800 kg/m^3 or less. Expanded polystyrene is used in large amounts as a packaging material, and is non-biodegradable. Overseas, lightweight concrete is used for precast panels (Building Systems Technology, 1992). However, this concrete cannot be considered for structural applications, due to its low compressive strength and a relatively high drying shrinkage (Park and Chisholm, 1999).

3.4 CIEMA

The Cement Industry Energy Management Association (CIEMA), was founded in 1994, with the aim of improving energy efficiencies within the industry. Its current members are the two cement manufacturers (Milburn Cement and Golden Bay Cement), the Energy Efficiency and Conservation Authority (EECA), and Eco-Logic (formerly Maruia Society). Formed as a response to the Kyoto Protocol, it was one of the first New Zealand industries to set up a Voluntary Agreement, in 1995, with central government to improve energy efficiencies. The target CIEMA set was to improve energy efficiency per unit output by 20% by the year 2000. Along with this, a 12% reduction in CO_2 emissions target per unit produced was set for the period 1990 – 2000.

The cement industry was able to meet (and exceed) their CO_2 savings target for 2000, based on their projections (CIEMA, 2000), which have proved to be extremely accurate. Since 1990, across the cement industry, thermal energy consumption has been reduced by 7%, electricity consumption has dropped by 8%, and CO_2 emissions have decreased by over 13%. The reasons for these improvements include (CIEMA, 2000):

- raw material changes (i.e. the use of GP blended cements)
- capital equipment upgrades to improve electrical and process efficiency
- use of substitute fuels, which give rise to lower CO_2 emissions and also a reduction in the grinding energy for coal.

4. RAW MATERIAL REQUIREMENTS + TRANSPORTATION

4.1 Product Characteristics

The specific product characteristics for each of the seven concrete products are detailed below.

A) The **ready-mix** water to cement ratios for the 17.5 MPa, 30 MPa, and 40 MPa strengths have been assumed to be 0.75, 0.59 and 0.45 respectively. Sand is a maximum of 5 mm in diameter; fine aggregate is nominally 13 mm in diameter, while coarse aggregate is nominally 20 mm in diameter.

B) The typical **double tee beams** are assumed to be loaded with a total load of 3.25 kPa, made up of a 0.75 kPa dead load and a 2.5 kPa live load. The Double Tee beam is 11.9 m long, and 2.4 m wide, and 0.31 m deep. It contains 0.244 cubic metres of 40 MPa concrete per lineal metre.

C) The typical **hollow core** (also called hollow core slabs or hollow core deck) is assumed to be similarly loaded as for the double tee beams (with 3.25 kPa total load). It has dimensions of 5.988 m long, 1.2 m wide and 0.3 m deep, with a cross-sectional area of 166 992 mm^2. It contains 0.167 cubic metres of 40 MPa strength concrete per lineal metre.

D) For **concrete blocks**, assume a 'standard whole' is used, whose nominal dimensions are 200 x 200 x 400 mm, with 35 mm thick walls and 50 mm thick webs made with 1950 kg/m^3 density concrete. The block weight is 13.55 kg. One cubic metre of concrete will yield 136 blocks of that size. The 'standard whole' block is typically made from 4 parts mortar sand, 1 part cement and ¼ part hydrated lime (Firth, 1999).

E) The **mortar** has the mix proportions of 1 part cement to 0.5 parts lime to 4.5 parts sand (Cement and Concrete Association Bulletin, 1988).

4.2 Raw Material Requirements

Table 1: Raw material requirements by concrete product (kg/m^3).

RAW MATERIAL	PRODUCT (kg of raw material per cubic metre of concrete)						
	17.5 MPa	*30 MPa*	*40 MPa*	*Double Tee Beam*	*Hollow Core*	*Block*	*Mortar*
20 mm aggregate	723	743	758	-	-	-	-
13 mm aggregate	233	252	268	1,060	1,060	-	-
Sand	891	845	801	800	800	1,652#	1,445
Cement	229	300	381	430	430	160	384
Lime	0	0	0	0	0	40	97
Total Water	172	172	172	165	165	128	174
TOTAL	2,248	2,312	2,380	2,455	2,455	1,980	2,110

graded (blended) aggregate – strictly not a sand, nor a fine aggregate.

Note:

- Not included in Table 1 are details on steel reinforcing, used within the precast products. This is discussed in the following section.
- Admixtures (which are materials added to wet concrete at the mixing stage to modify its wet or hardened properties) are used within the mix design, and are also excluded from Table 1. The reason for this is detailed in Appendix E.
- 'Total water' is an aggregate of batch water and the water contained within the aggregate. Batch water is only the amount of water added to the mix, and does not include the water contained within the aggregates (which makes up about 5% of their weight). Batch water typically equates to around 100 l/m^3, and is dependent on the moisture content of the aggregates and sand used at the time of batching.

4.3 Other Material Requirements

The two precast products also have a considerable amount of reinforcing steel within them. To be consistent with Forintek (1993) methodology, only the major steel reinforcing strands have been accounted for in this study – thus mesh, stirrups, ties and secondary reinforcing are not included. The estimates of the amount of reinforcing steel within the precast units are assumed to be an indication of industry 'averages' (i.e. typical loadings) with a live loading of 2.5 kPa, and a superimposed dead loading of 0.75 kPa.

4.3.1 Double tee beams

Total volume of rebar is 2.18 x 10^7 mm^3. This equates to 13.7 kg steel per lineal metre of double tee, compared to Forintek's (1993) 12 kg steel per lineal metre.

4.3.2 Hollow core

Six no.12.9 strands (i.e. about 13 mm in diameter) support the loading. The strands have a combined cross-sectional area of 1.06 x 10^6 mm^3. This equates to 7.95 kg steel per metre length of hollow core (compared to Forintek (1993) at 7 kg of steel per lineal metre).

4.4 Raw Material Transportation Mode and Distances

For most regions in New Zealand, the supply of raw materials is in close proximity to the ready-mix and precast industries. The following raw material transportation distances were estimated based on a survey of ten concrete plants, and communication with experts in the industry. In keeping with previous Forintek methodology, the return transportation journey is included in the assessment. Two examples of transport modes and distances are given below:

For 17.5 MPa concrete:

- For **sand**, the weighted average return distance is 51 km, by diesel truck.
- For **fine aggregate** (13 mm in diameter) and **coarse aggregates** (20 mm in diameter), the weighted average return distance is 26 km, by diesel truck.
- For **cement**, the average return distance is 526 km by diesel truck, and 706 km by ship.

For the precast plants:

- For **reinforcing steel**, the average return transportation distance is 10 km by diesel truck, 474 km by train, and 164 km by ship, assuming all reinforcing steel is sourced from Pacific Steel in Auckland. For a breakdown by mode of transport, see the Appendices.

5. ENERGY USE

This section deals with the estimation of energy use for the seven concrete products examined. The estimates include the energy used to extract, transport and process the major contributing materials used within each type of concrete product. The boundary for this analysis (as for the previous BRANZ LCI studies) is at the plant gate of the ready-mix or precast facility. No allowances were made for the transportation of the final product to the construction site.

A summary of energy-use related figures by product and stage can be found in Table 19 to Table 25. Note that they may differ slightly to the numbers within this section, due to rounding.

5.1 Updating Cement Figures

For two of the 'raw' ingredients, reinforcing steel and cement, estimates have been based on previously conducted studies. For the reinforcing steel, Pacific Steel energy and emission figures were used, since they supply the bulk of New Zealand's reinforcing steel (refer Jaques, 2002). For the cement energy use figures, a major upgrade of the 1995 figures used in the 1998 LCI study (Jaques) was necessary for several reasons:

1. A major restructuring of the cement industry, including the closure of Lee Cement (one of the three cement plants operating at the time), formerly operating out of Nelson.

2. Significant changes in the manufacturing process, most notably the increased use of blended cements, as a result of the introduction of NZS 3122 (1995). Both cement manufacturers (Milburn and Golden Bay Cement) are currently using limestone as their filler.
3. Significant energy efficiency improvements to the manufacturing process.
4. The change of use in fuel types.

This update concentrated on cement's manufacturing stage, mainly for two reasons:

- it accounts for the bulk (greater than 90%) of the emissions and energy use
- the manner of extraction and transportation of the raw materials of cement have changed very little.

The new use of limestone as a filler in cement was taken into account simply by reducing the energy input at the manufacturing stage by the weight of limestone added. This was possible as limestone has minimal associated manufacturing energy requirements. The limestone filler is added at the very end of the cement manufacturing process – with only a very small amount of extra grinding energy required. Grinding energy has been taken into consideration, and estimated to equal 172 MJ/t (Process Developments, 1995).

The new energy (and therefore emission) figures were a significant improvement on those derived in the previous cement study, with more accurate estimations of (for example) fuel types available. In 1999 information was sourced for energy use, fuel types and production output of the two remaining cement plants. The figures used were normalised by output, based on the assumption that cement used within New Zealand is directly proportional to the amount of cement made by each plant. Allowances were made for imports (4975 tonnes) and exports (68217 tonnes) of cement in 1999 (Statistics New Zealand, 2000). Also, it should be noted that the use of post-consumer waste oil to supplement standard kiln fuel, is considered to be 'free input' by convention (Forintek, 1993a; Appendix A, pg 19), where only *"transport energy and the environmental impact of its use in the new process...."* is environmentally counted.

The new nationally weighted average cement embodied energy is 4.518 MJ/kg, which has allowances for the energy associated with raw material extraction, transportation of the raw materials to the cement plants, and a small amount of waste (1%). The allowances are based on a previous cement LCI study (Jaques, 1998). This total embodied energy figure is a reduction of energy intensity of 15% from the 1998 report due to the new use of limestone fillers and the treatment of all post-industrial fuel oil as 'free input' – having no associated energy costs.

Note: Table figures in report may not add up exactly due to rounding errors.

5.2 Raw Material Extraction and Primary Processing

As for the previous BRANZ LCI study of cement (Jaques, 1998), little New Zealand-specific data could be sourced on the quarrying and crushing of the various raw materials required for concrete. It was decided to reuse a 'blanket' embodied energy value of 0.074 MJ/kg for raw material extraction, applied by Alcorn (1995). This is a general figure for mining and quarrying industries. It has been assumed that all quarrying machinery is diesel run, with the energy figure inclusive of a small amount for primary processing. The only 'mined' raw material that this figure doesn't apply to is sand, which has minimal energy requirements associated with its extraction and primary processing.

Table 2: Raw material extraction-related embodied energy.

RAW MATERIAL EXTRACTION AND PRIMARY PROCESSING OF CONCRETE		
Raw Material	**Energy Intensity**	**Fuel Type**
Coarse aggregate	0.074 MJ/kg	Diesel
Fine aggregate	0.074 MJ/kg	Diesel
Limestone	0.074 MJ/kg	Diesel
Sand	0.0	-

5.3 Raw Material Transportation

The transportation of the raw materials has been divided into ready-mix-related materials (aggregate and cement), and non-ready-mix materials (reinforcing), for clarity.

5.3.1 Transporting aggregates and cement

The source for a particular aggregate is dependent on the grade of the concrete produced. This is reflected in the energy requirements, which vary with concrete type. In all, four separate raw material transportation calculations were used. The calculations used were separated into the four categories:

1. 17.5 MPa ready mix
2. 30 MPa ready mix
3. 40 MPa ready mix, which equalled the (equivalent strength) precast products
4. mortar and block mixes.

The 40 MPa/precast transportation figures are shown as an example in Table 3.

Table 3: Transportation of (40 MPa pre-cast) concrete raw materials to concrete plant.

'RAW' MATERIALS TRANSPORTATION-RELATED ENERGY REQUIREMENTS			
Concrete Product	**Raw Material**	**Mode - Fuel**	**Energy Use (MJ/kg)**
40 MPa / Precast	Coarse Aggregate	Truck (diesel)	0.0100
	Fine Aggregate	Truck (diesel)	0.0030
	Sand	Truck (diesel)	0.0156
	Cement	Truck (diesel)	0.0062
		Ship (heavy fuel oil)	0.0138
		TOTAL	**0.0486**

5.3.2 Transporting the reinforcing steel

An average embodied energy intensity for transportation of reinforcing bar (rebar), was estimated for inclusion into the precast concrete products.

The resulting embodied energy summary by mode of transport for rebar can be seen in Table 4. For details on its generation, refer Appendix D.

Table 4: Weighted average transportation-related embodied energy for reinforcing bar.

STEEL REINFORCING EMBODIED ENERGY	
Mode	**Embodied Energy (MJ/kg)**
Truck	0.0120
Train	0.2321
Ship	0.0197

5.4 Ready-Mix Concrete

Energy use estimates for ready-mixed concrete were developed for each stage of activity (i.e. raw material extraction including primary processing, raw material transportation and manufacturing) as follows:

Raw Material Extraction

Raw material requirements in kg/m^3 of concrete were based on production-weighted averages for the seven plants examined (five in Auckland, one in Wellington and one in Palmerston North) and were multiplied by the energy requirement estimates shown in Section 5.2. Following is an example calculation for 17.5 MPa ready-mixed concrete. The same process was used for the other concrete strengths.

17.5 MPa Ready-mixed concrete energy use for extraction

Raw material	kg/m^3 of concrete	MJ/kg	MJ/m^3 of concrete
Coarse Aggregate	723	0.074	53.502
Fine Aggregate	233	0.074	17.242
Sand	891	0	0
Cement	229	N/A	N/A
		TOTAL	**70.744**

Note: some figures in these Tables may not add up due to rounding errors.

Raw Material Transportation

The same approach was used to estimate raw material transportation energy requirements for ready-mixed concrete, as illustrated in the following example for 17.5 MPa ready-mix.

17.5 MPa ready-mixed energy use for raw material transportation

Raw material	kg/m^3 of concrete	MJ/kg	MJ/m^3 of concrete
Coarse Aggregate	723	0.01053	7.61608
Fine Aggregate	233	0.00306	0.7129
Sand	891	0.02385	21.250
Cement (truck)	229	0.00387	0.88714
Cement (ship)	229	0.00895	2.05046
		TOTAL =	32.517

Manufacturing

The same approach was used for generating energy requirements per tonne of ready-mixed concrete, with the energy intensities, by fuel type, listed below:

Fuel Type	MJ/kg
Diesel	0.055
Electricity	0.0169
TOTAL	**0.0719**

Converting 0.0719 MJ/kg into volumetric terms, this equates to 161.6 MJ/m^3 for the 17.5 MPa (with density = 2248 kg/m^3); 166.2 MJ/m^3 for the 30 MPa (density = 2312kg/m^3), and 171.1 MJ/m^3 for the 40 MPa concrete (density = 2380 kg/m^3).

Manufacturing electricity use is for concrete mixing, office equipment, water pumps, and incidentals. Diesel use is for loaders, back-up engines and such-like. This manufacturing embodied energy estimate has been applied to all three ready-mixed concrete strengths, and was based on the average figures of a medium-sized, batch-mixed, ready-mix plant located in Wellington (Campbell, 2000).

The 'cement' embodied energy figure is the upgraded (1999) figure that accounts for all the efficiency improvements detailed in Section 5.1. Combining the new cement embodied energy (4.518 MJ/kg) with the cement contents of 229, 300, 381 kg/m^3 in the 17.5, 30, and 40 MPa mixes respectively, then:

Table 5: Energy use in ready-mix concrete production, by stage (MJ/m^3).

Strength (MPa)	Raw Material Extraction	Raw Material Transportation	Cement	Manufacturing Process	TOTAL
17.5 MPa	70.74	32.52	1035	161.6	**1360.86**
30 Mpa	73.63	27.61	1355	166.2	**1703.44**
40 Mpa	75.92	28.49	1721	171.1	**2099.51**

5.5 Precast Concrete

Hollow core and double tees typically use high strength 40 MPa concrete (Chisholm, 1999). Their mix designs are quite different from that of a similar strength ready-mix concrete, due to the requirements of a much higher initial strength gain. This is achieved by the use of additives, and/or heat curing, so that the precast concrete can attain 30 MPa in the first 18 hours.

Raw Material Extraction and Processing

Raw material	kg/m^3 of concrete	MJ/kg	MJ/m^3
Coarse Aggregate	268	0.074	19.832
Fine Aggregate	758	0.0740	56.092
		TOTAL =	75.924

Raw Material Transportation

Raw material transportation energy requirements were estimated using the raw material requirements (Table 1) multiplied by the transportation energy intensities in Appendix B.

Raw material	kg/m^3 of concrete	MJ/kg	MJ/m^3
13mm Aggregate	1060	0.0030	3.18
Sand	800	0.0156	12.48
Cement (truck)	430	0.00619	2.6617
Cement (ship)	430	0.01380	5.934
		SUB-TOTAL	*24.256*
Steel for hollow core	47.6	0.2640	12.566
Steel for double tee	56.2	0.2640	14.837
	TOTAL	**Hollow Core**	**36.822**
	TOTAL	**Double Tee**	**39.093**

Manufacturing

The energy required for handling and mixing the precast concrete (whether for double tees or hollow core) and for vibrating the forms is assumed to be the same as for precast concrete pipe. The following estimates were taken from Holderbank (1992), based on the density of 40 MPa concrete.

	MJ/kg
Electricity	0.0390
Diesel Fuel	0.0320
TOTAL	**0.0710**

Converting 0.071 MJ/kg into volumetric terms, this equates to 174.3 MJ/m^3 based on the density of 2455 kg/m^3 for 40 MPa concrete.

Although curing energy (for artificial heating) is used for some pre-stressed structures, which are precast, this practice is common in most parts of New Zealand south of Auckland (Chisholm, 1999). If precast heating is used, then it is performed by the hot water or steam methods. However, since the process is not standard, curing heat has not been included for this study.

Reinforcing Steel Contribution to Precast Unit

Pacific Steel uses 8.6 MJ/kg for the manufacture of its reinforcing steel (Alcorn and Baird, 1996). The transportation component (from steel plant to precast manufacturer) is 0.264 MJ/kg and is addressed separately; refer Appendix D. Approximately 47.6 kg/m^3 of steel is used in the standardised hollow core precast units, and 56.2 kg/m^3 of steel is used in the standardised double tee unit examined. This gives a total steel-related energy use of:

	MJ/m^3
Hollow Core	409.4
Double Tee	483.3

Note that these figures only incorporate the main strands of steel, excluding the stirrups and the mesh (in keeping with Forintek's approach). Stirrups and mesh account for a significant amount of steel - about 50% extra.

Precast Summary

The final energy estimates for the precast products are shown in Table 6 and in the Appendices (where they are expressed in MJ per lineal metre rather than in MJ/m^3). The estimates were first developed volumetrically and then converted to lineal units using the following factors:

1 lineal metre of double tee requires 0.244 m^3 of concrete; and
1 lineal metre of hollow core requires 0.167m^3 of concrete.

Table 6 summarises the embodied energy requirements for the precast units, by stage.

Table 6: Energy use in precast production, by process stage.

Energy Use in Precast Production, by Process Stage (in MJ/m^3)						
Stage	Raw Material Extraction	Raw Material Transportation	Cement Manufact.	Concrete Manufact.	Steel Manufact.	Total
Double Tee	75.92	39.1	1,943	174.3	483.3	**2,715.62**
Hollow Core	75.92	36.8	1,943	174.3	409.4	**2,639.42**

Note:

1.Raw material extraction includes some primary processing, as discussed in section 5.2.

2.Raw material transportation includes transportation of rebar.

5.6 Concrete Blocks

Raw Material Extraction and Processing

For the embodied energy estimation, the following (uncompacted) densities were applied: sand = 1245 kg/m^3; cement 1175 kg/m^3 and lime 640 kg/m^3. It is assumed that the specific graded (blended) aggregate used for concrete blocks has the same extraction and primary processing energy requirements as for the sand (i.e. nil). Therefore, the raw material extraction and primary processing for concrete blocks is nil also, for all but the limestone, which is 2.96 MJ/m^3.

Raw Material Transportation

Raw material transportation energy requirements were estimated by using a simple average of the three ready-mix strengths. The transport energy use for graded (blended) aggregate and the limestone was assumed to equal the average transport energy use for aggregate.

Raw material	*kg/m^3 of concrete*	*MJ/kg*	*MJ/m^3*
Graded Aggregate	1652	0.0238	39.318
Cement (truck)	160	0.005	0.801
Cement (ship)	160	0.011	1.813
Limestone	40	0.003	0.120
		TOTAL	42.132

Note: *Some figures in these Tables may not add up due to rounding errors.*

Manufacturing

A similar approach was used for generating energy requirements for mixing of concrete block as for ready-mixed concrete. However, New Zealand-specific energy requirements for the mixing and curing of blocks could not be obtained. Forintek's figures, based on North American data, were substituted, as it was assumed that there are likely to be only superficial differences between the two countries' methods of manufacturing. The energy intensities by fuel type are listed below:

Fuel Type	**MJ/kg**
Diesel	0.127
Electricity	0.064
Natural Gas	0.473
TOTAL	**0.664**

Converting 0.664 MJ/kg into volumetric terms, this equates to 1288 MJ/m^3 based on the block density of 1980 kg/m^3. In summary, the embodied energy intensities are shown by stage, in Table 7.

Table 7: Energy intensity for concrete block, by stage.

Material	Raw Material Extraction	Raw Material Transportation	Cement	Manufacturing Process	TOTAL
Concrete Block (MJ/block)	0.00	0.31	5.31	9.67	15.29
Concrete Block (MJ/m^3)	3.00	42.1	722.8	1,315	2,082.9

5.7 Cement Mortar

Cement mortar is used as a horizontal and vertical layer between successive concrete blocks. To be consistent with the Forintek studies (1993 and 1993a), concrete infill was not included in this report. Its composition has been sourced from NZS 4210: (SNZ 1989) where a typical mortar mix proportion is given as:

Table 8: Typical mix design of mortar (NZS 4210).

Durability	Cement	Hydrated Lime	Sand
Very high	1	0 – 0.25	3
High	1	0.5	4.5
Medium	1	1	6

For this study, the 'high durability' mix design was chosen (being an average mix). The percentage values are therefore: Cement = 16.7%; Hydrated Lime = 8.3% and Sand = 7.5%.

Raw Material Extraction and Processing

The extraction and primary processing energy requirements for cement mortar are shown below, with lime extraction embodied energy assumed to be the same as for aggregate.

Raw material	*kg/m^3 of concrete*	*MJ/kg*	*MJ/m^3*
Sand	1445	0.0	0
Lime	97	0.074	7.178
		TOTAL	7.178

Raw Material Transportation

Raw material transportation energy requirements were estimated using the energy use per tonne factors in Table 4. Nationwide averaged transportation distances were used. The transportation energy intensity for lime is assumed to be equal to that of sand, on a volume basis.

Raw material	*kg/m³ of concrete*	*MJ/kg*	*MJ/m³*
Sand	1445	0.0189	27.311
Cement	384	0.0163	6.2592
Hydrated Lime	97	0.0029	0.291
		TOTAL	33.861

Manufacturing

The mixing of mortar (which is usually performed on the building site) is accounted for in this study, although it is technically out of the study's boundary. It is assumed to take the form of a 0.085 m³ mixer driven by a 560W electric motor, with a mix time of 10 minutes. Thus, the total electrical energy use per cubic metre of mortar is (after Forintek):

560 x 3.6 MJ/kWh = 2.016 MJ, or 0.336 MJ/mix or 3.95 MJ/m³.

In summary, the embodied energy intensities are shown by stage, in Table 9.

Table 9: Energy intensity by stage for mortar (MJ/m³).

Material	**Raw Material Extraction**	**Raw Material Transportation**	**Cement**	**Manufacturing Process**	**TOTAL**
Mortar (MJ/m³)	7.2	33.9	1,735	3.95	1,780.05

6. WATER USE

6.1 General Water Use

Water is an essential ingredient in the production of concrete, constituting around 7.7% by weight of the total raw ingredients in standard 17.5 MPa ready-mix. Water use can be broken down by type: concrete batching water, central mixer washout, exterior truck washout, interior truck washout, and miscellaneous plant uses. The flow-diagram represented by Figure 2 below shows the main water flows in the ready-mix industry.

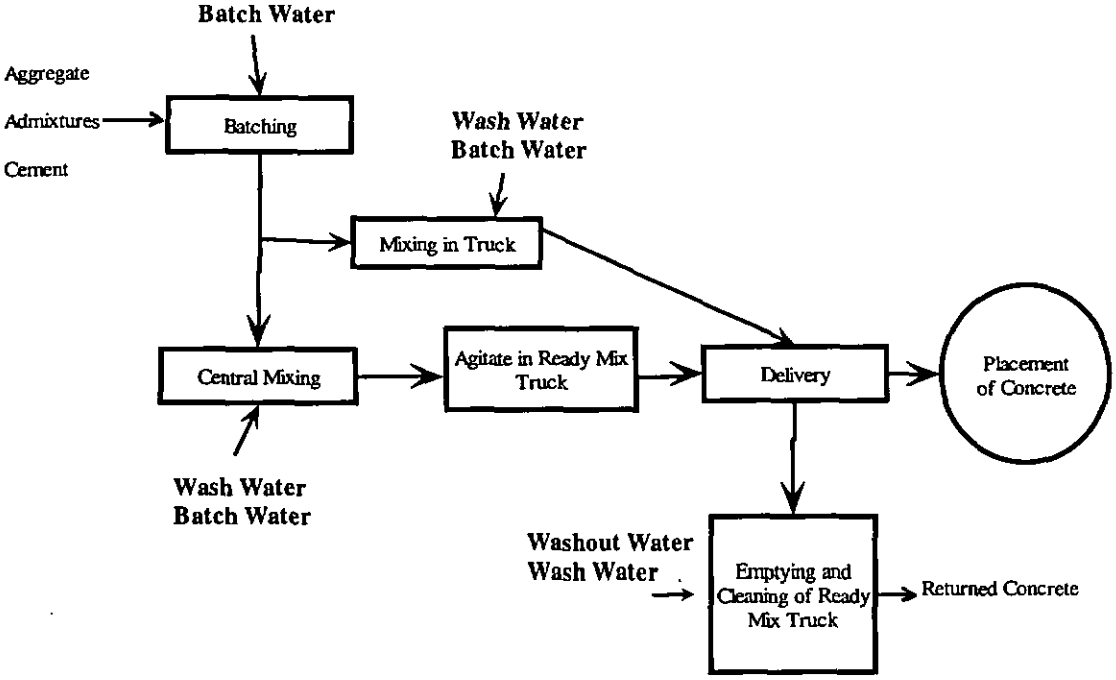

Figure 2: Water use in the NZ ready-mix industry (adapted from Forintek, 1993).

As part of the BRANZ questionnaire for ready-mix operators (refer Appendix A), the current and future use of water in the concrete industry was examined. It was found that:

- water use varied considerably by ready-mix plant – anywhere from 176 kg litre per cubic metre of concrete through to 960 kg per cubic metre of concrete produced.
- there is little use of storm water produced on-site as an alternative to main sources (whether town or river sourced).
- on-site recycling of water is practised by all of the plants surveyed.
- most plants intend to recycle more water in the future.

Given the large variations in water use figures, it is difficult to determine an average figure, based on the data available. However, it seems that these New Zealand figures align well with those of Forintek (1993), where a range of between 174 and 703 kg of water per cubic metre of concrete produced was cited. More research would be necessary to determine averages from the New Zealand study.

There have been some international studies carried out on waste-water produced as part of normal operations in the ready-mix industry. It was found that there was a large variation of water use between plants and countries. A Scottish study (Souwerbren,

1996) stated *"no less than 56% of the total quantity of waste water produced in the ready-mixed industry consists of wash water"*. The corollary is that at the very most, 44% of the water is used for batch water. Examining Forintek's (1993) figures, batch water accounts for 37%, based on high/low medians. The US Environmental Protection Agency (1978) states that the mean volume of wastewater was less than 50 litres/m^3 for ready-mixed concrete – 80% of which is washout water – based on a survey of 385 plants.

There has been also some research on the use of waste water in New Zealand. Park and Chisholm (1996) state that 200 litres of water is used to produce a cubic metre of concrete from a central batch plant, while for a truck mixer plant, 300 litres is required. This doesn't include 500-1000 litres of water to wash down the plant and yard each day, and 100 litres for daily mixer washing.

A more detailed examination of three ready-mix plants was performed as part of this LCI study, to further sub-divide waste water quantities by type. As a result of this investigation, Table 10 was derived.

Table 10: Estimated water use in New Zealand ready-mix industry.

Water Use Category	New Zealand (litre/m^3)
Batch Water	100
Truck Wash-off	8
Truck Washout	8
Miscellaneous	60
TOTAL	**176**

Note: Truck washout and wash-off figures were aggregated, so a 50/50 split between the two was made.

6.2 Liquid Effluents

Contaminated wastewater from concrete production is a concern for New Zealand Regional Councils, who have under the Resource Management Act (1991) a responsibility towards mitigating the effects of activities, not just the activities themselves. The Resource Management Act identifies a number of types of resource consents for pollutants, of which a 'discharge permit' is one. Consents are required where an activity contravenes the restrictions outlined within the Act. According to the Wellington Regional Council (Correy, 2000) ready-mix plants in the area perform their own end-of pipe monitoring, with most plants discharging into the ground. However, this end-of-pipe monitoring for liquid effluents is minimal, with the plants examining only the resultant pH level (within the waste water), along with perhaps some suspended solids monitoring. Forintek (1993) considered a number of contaminants within wastewater, including: suspended solids, aluminium, oil, grease, chlorides, and sulphates.

It was decided for this report not to provide any data on contaminants in liquid effluents for the New Zealand case, due to the paucity of data available, which could misrepresent typical figures.

7. DISCHARGES TO AIR

This section details the derivation of the main atmospheric emissions associated with the manufacture of concrete for each of the three life stages addressed. Thus air emissions resulting from raw material extraction, transportation and final production are examined. With one exception (particulate emissions) the bulk of the atmospheric emissions in the manufacture of concrete are the result of fuel use. The emissions examined in this LCI are: carbon dioxide, carbon monoxide, methane, nitrous oxides, volatile organic compounds, sulphur dioxide and total particulate matter.

The cement-related atmospheric emissions are examined first.

7.1 Deriving Cement-Related Atmospheric Emission Figures

All raw material extraction and transportation – related atmospheric emission figures were taken directly from the BRANZ cement LCI study (Jaques, 1998). These emission figures were derived from overseas generic figures, which approximate the energy used for a specific operation or haulage distance. This contrasts with the manufacturing-related emission figures, which are based on specific plant process analysis. For both New Zealand cement plants, there have been significant manufacturing-related changes, mostly as a result of changes in fuel mix and energy efficiency improvements (see Section 5.1).

- CO_2 in the manufacture of cement is generated from two sources – that produced as a result of thermal processing and that produced in the calcination process when calcium carbonate ($CaCO_3$) breaks down to calcium oxide (CaO). The CO_2 emission factor due to thermal processing is dealt with later in this section. The calcination emission factor was assumed to be 0.498 tonnes of CO_2 per tonne of cement produced, which is derived from dividing the molar mass of carbon dioxide by the molar mass of calcium oxide and multiplying this by the fraction of CaO contained in cement (i.e. 0.635, which is an average of established figures by Gagan (1974)).

- NO_x emission from the manufacturing stage of cement is based on three mechanisms:
  - o *thermal* NO_x (produced under fuel-lean conditions by high temperature reaction)
  - o *prompt* NO_x (produced under fuel rich conditions), and
  - o *fuel* NO_x (formed when nitrogen in the fuel reacts to form hydrogen cyanide).

  NO_x emissions are dependent on fuel type and kiln type (Queen, 1993). Coal fired cement kiln NO_x emissions vary between 1 and 4 kg NO_2/t clinker. Very little data on cement-related NO_x emissions could be sourced for the New Zealand case. As a result, the New Zealand NO_x emission figures were based on overseas research. The NO_x emission from cement kilns are estimated to be 1827 g/t of cement for the Milburns wet process and 1503 g/t for Golden Bay Cement's preheater process, both using (mainly) coal fired kilns (using Forintek, 1993). A weighted average (based on output) of the two cement plants operating in New Zealand, was used in this LCI study. To this figure, fuel-related NO_x emissions as a result of raw material extraction and transportation, were added. No allowance was made for NO_x control technologies (either combustion or post combustion). This area could be further explored in the future.

- Oxides of sulphur are generated by the combustion of sulphur in fossil fuels and the oxidation of sulphates, sulphides and organic sulphur in the cement raw materials. Limestone chemically reacts with SO_2, significantly reducing the actual amount of SO_2 released during the manufacturing process. It has been estimated that this chemical reaction results in 96.12% of the total fuel sulphur input being contained ('scrubbed') within the limestone, rather than being released (Gagan, 1974). This 'net' figure was applied to this study.

- For derivation of the raw material extraction and transportation cement-related emissions to air, refer to the BRANZ cement LCI study (Jaques, 1998).

7.2 CO_2 Emissions From Coal During Cement Manufacture

In energy terms of cement production, coal is the single most important fuel, contributing over 80% of the energy required for its manufacture (Jaques, 1998). CO_2 emissions from coal use are primarily a result of having to thermally process the cement raw materials in the manufacture of clinker. Coal's significance is increased when its CO_2 emission factor is compared to others fuels – it is ranked top in terms of emissions per unit of energy delivered.

Accurately estimating the CO_2 emissions from burning coal is no simple matter. Coal is a non-homogeneous substance, with a varying composition (Baines, 1993). Coal's CO_2 emission factor (which indicates the amount of carbon dioxide released into the atmosphere when the coal is burnt) is dependent on its calorific value. Calorific values vary between mines within a region, and also may vary within a mine seam (Baines, 1993).

The calorific value of coal is determined by four factors:

1. the proportions of carbon, hydrogen and sulphur, and other combustible matter in the coal
2. the amount of moisture in the coal
3. the completeness of combustion, and
4. the amount of non-combustible matter present.

Trying to estimate the CO_2 emission factor for a particular mine site, given all the above variables, is difficult. For this LCI study, it was decided that a typical value for the particular classification of coal used in the cement industry be applied. The cement industry uses coal mainly sourced from the West Coast area, but other sources may be used when difficulties in supply occur (Bourke, 2000). West Coast coal is classified (i.e. ranked) as bituminous, having a gross calorific value (GCV) of around 32 TJ/kt, and an estimated (i.e. typical) CO_2 emission factor of 88.8 t CO_2 /TJ (after Whitney and Hennessy, 1990). This is the same value as used in the CIEMA annual reporting CO_2 estimations.

7.3 Concrete Product-Related Emissions

Generally, fuel-related atmospheric emissions for each stage were developed by applying the energy use estimates combined with the fuel-use emission factors, for each stage. For example, the CO_2 emission estimate for the extraction of coarse aggregate (nominally 19.5 mm in diameter) for 17.5 MPa ready-mix concrete is developed as a product of the raw material extraction intensity (0.074 MJ/t of diesel fuel use from Section 5.2) and the diesel emission factor (from Table 28) by the proportion of coarse aggregate within one cubic metre of concrete. The resulting CO_2 emission factor is 5.0 kg/m^3 of concrete.

For each of the seven concrete products, the energy requirements (and therefore the associated atmospheric emissions) for the raw material extraction and mixing were assumed to be the same per cubic metre. The exception to this was the transportation energy requirements, which varied according to where the raw materials were sourced from. For the precast products, atmospheric emissions associated with the transportation of reinforcing steel (from the steel plant to the precast plant) were included.

The author was unable to source any particulate (i.e. dust) emission figures for New Zealand-specific mining and concrete mixing, although New Zealand experts were consulted (St George, 1997). Two aggregate quarries within the Wellington Regional Council area were investigated to see if any plant-specific information on particulate matter could be collected. The two quarries were Owhiro Bay (Wellington South) and Dry Creek (North Wellington). Owhiro Bay quarry has no defined limits as to how much dust is allowed to be generated. For their stockpiles of aggregate, their consent requirements are conditional - "*dust conditions are reduced to a practical minimum*" (Correy, 2000). For the Dry Creek Quarry, rather than imposing a specific limit, the discharge permit states "*dust is not noxious, dangerous or offensive beyond boundary*".

Thus, all New Zealand particulate emission rates used in this study were based on North American figures (Forintek, 1993):

- aggregate extraction (equating to 50 g/tonne aggregate)
- cement manufacture (equating to 510 g/tonne cement)
- concrete products manufacture (120 g/cubic metre).

The final estimates for the emissions of each concrete product are shown in Table 12 to Table 18 in the Appendices.

8. SOLID WASTES

Solid wastes are generated in a variety of ways during the production of concrete. Wastes can be generated through the extraction of the raw materials (aggregate and sand), the production of the cement and steel, the transportation of all the materials and during the manufacture of the concrete itself.

8.1 Solid Wastes from Aggregate Extraction

Aggregate is usually quarried from surface deposits and requires washing, crushing and size separation. It is then used as is – with no further processing required. As a result there is little solid waste other than mine spoil; however, there are some fines present in the wash water. Since mine spoil is not considered to be waste (as defined by Forintek, 1993a), it is not included in this study.

8.2 Solid Waste from Concrete Manufacture

The solids waste that results from the manufacture of concrete can be grouped into five categories: central mixer wastes, ready-mix truck residue, sludges from settling ponds, off-specification products and excess material resulting from over-ordering. Increasing pressure from territorial and local authorities (mainly through the requirements of the Resource Management Act and higher landfill disposal costs), have put considerable pressure on concrete manufacturers to keep their landfill-destined materials to a practical minimum.

Little New Zealand-specific material published on solid wastes resulting from the manufacturing of concrete products could be sourced. A recent BRANZ report (Park et al, 1996), for example, states that the actual figure for excess (returned) concrete for New Zealand is not known. Based on overseas figures (Albeck et al, 1993) between 2-2.5% of the entire production volume is wasted due to over-specification. Applying this figure to New Zealand concrete output in 1999 of around 3.36 Mm^3 or approximately 8.1 Mt (NZ Concrete, 2000), this equates to 162 kt – 203 kt of concrete.

Most New Zealand plants are now either reclaiming their wastes (a form of recycling) or using their excess materials for constructive purposes. Some New Zealand plants recycle their returned fresh concrete through a reclaimer, which separates out the aggregate and coarse sand proportions from waste concrete (Park and Chisholm, 1996). To quote *"the remaining liquid and fines go into the wash water recovery system and end up in the slurry water component. The recycled sand and aggregate can be regraded through the concrete aggregate processing plant"*. Many plants also have a cubic metre moulding for setting concrete in. Once the concrete is set, it can be used for rip-rap (river bank erosion protection) or bin dividers for various applications.

As part of the BRANZ questionnaire sent to ready-mix plants (refer Appendix A), operators were asked to estimate the percentage of returned concrete, as part of normal operations. This waste only includes over-specification and off-specification product. The estimated percentages for the five ready-mixed plants ranged from less than 1% through to 2.5%. A weighted average (based on plant output) was calculated to be 1.1%, and was applied to the waste estimations used in this study. Where New Zealand-specific figures could not be gained, overseas figures were used:

1. With returned concrete estimated to be 1.1% for New Zealand, and densities of 2.2, 2.35 and 2.4 t/m^3 for the 17.5 MPa, 30 MPa and 40 MPa ready-mixed concrete respectively, this equates to 24.2 kg, 25.9 kg and 26.4 kg of returned concrete waste. Assuming that (conservatively) 70% of this is reused in some way, then the net amount actually wasted equates to 7.2 kg, 7.8 kg and 7.9 kg respectively for the three ready-mix strengths.

2. Estimated solid wastes from truck washout water is 21 kg per cubic metre of ready-mixed concrete (Forintek, 1993). This is based on truck washout generating 59 kg of waste per washout per cubic metre of mixer volume, and an average of 1.5 washouts per day.

3. It is estimated that only about 30% of the New Zealand ready-mix plants are centrally mixed with the remainder made up of truck-mixers (Chisholm, 1999). For the central mixer washout, it is estimated that 11 kg of solid waste per cubic metre of concrete mixed is expected. This is based on estimations of 73 kg of washout per cubic metre of mixer capacity (Ross and Shepherd, 1988). Averaged over all the operations, 3.3 kg/m^3 of solid waste is generated.

4. For the precast units, masonry block and cement mortar, their waste generation is assumed to be less than their ready-mix counterparts, due to increased controls during manufacture. Assuming the wastes for equipment washout for precast materials is similar to that for the central mixed ready-mix plant (11 kg/m^3), the overall waste by-product can be estimated.

Amalgamating these waste figures, an estimation of the solid wastes resulting from each of the concrete products is shown in Table 11.

Table 11: Solid waste due to concrete product manufacture – including over-specification, off-specification, and mixing residue.

Concrete Product	Solid Wastes
17.5 MPa	31.5 kg/m^3
30 MPa	32.1 kg/m^3
40 MPa	32.3 kg/m^3
Double tee beam	2.684 kg/lineal metre
Hollow core	1.837 kg/lineal metre
Cement block	0.081 kg per block
Mortar	11 kg/m^3

Note:

It should be noted that in (4) above, although Forintek (1993) methodology has been applied, the results for this BRANZ LCI study differ from their results. It seems that the Forintek document has applied an erroneous figure for solid wastes generated as part of precast production. Forintek have assumed that "*...equipment washout for precast and concrete blocks is similar to that for the central mixer of a ready-mix operation*" (pg 88). They then give the figure of 2.59 kg/m^3 of concrete waste generated, which was calculated based on the proportion of centrally-operating ready-mix plants to dry batch plants. In dry-batch plants, mixing is performed within the ready-mix concrete trucks. However, this proportion should not be factored into the estimation for precast plants, for all the mixing would be performed in central mixers. Forintek's error is carried through to their results in Table 15.2 (pg 88) and summary Table 16.12 (Forintek, 1993).

9. COMPARISON WITH INTERNATIONAL STUDIES

There has been a range of LCI-based environmental studies on concrete, using actual material and energy flows. However, it is difficult to compare many of the international studies with this study, due to the lack of transparency or the differing boundaries used. Even comparisons with the Forintek figures are problematic, due to the following factors:

1. Forintek broke down their figures by six key cities – Vancouver, Calgary, Winnepeg, Toronto, Montreal and Halifax. To avoid having the task of averaging them all for a New Zealand comparison, the city of Toronto (which had an inventory closest to the average of the whole country) was used.
2. Comparisons for double tee, hollow core and concrete block products are coarse due to the slightly different end-products being manufactured. For example:
   - *Standard concrete blocks* – Canadian blocks are larger, with only 104 made per cubic metre of concrete, versus 136 New Zealand blocks.
   - *A typical double tee beam* in Canada requires 0.297 m^3 per lineal metre of 35 MPa concrete, versus New Zealand's 0.244 m^3 per lineal metre of 40 MPa concrete.
   - *Typical hollow core* – in Canada uses 0.170 m^3 of 35 MPa concrete per lineal metre, versus New Zealand's 0.167 m^3 of 40 MPa concrete per lineal metre.
3. New Zealand's 40 MPa ready-mix concrete has no Canadian counterpart, as the highest strength Canadian concrete examined was 30 MPa (cylinder strength). Similarly, New Zealand's 17.5 MPa strength concrete did not have a corresponding Canadian strength concrete, therefore Forintek's 20 MPa concrete inventory figures were used.
4. Canadian figures are all based on pre-1993 production processes, and are likely to be 10-15% more energy intensive (with implications for atmospheric pollutants) than they are now, given improvements in energy efficiencies, effluent and atmospheric emission technologies etc.
5. All of the mix designs for each of the seven products were (in some cases widely) disparate. This issue has been elaborated upon in the comparisons.

9.1 Emissions to Air

Excluding the total particulate matter (TPM), all the atmospheric emissions result from the burning of fuel. However, during the production of cement, three pollutants - CO_2 SO_2 and NO_x - are altered by chemical and/or pyro-processing, resulting in a net increase or decrease of pollutant. The resulting net releases have been accounted for in this New Zealand study.

Note that the New Zealand atmospheric emission figures are only an indication of the actual figures, as they do not account for filters, converters of other methods of reduction used as part of the environmental mitigation processing. It is unknown just what influence emission control technologies have on reducing the overall pollutant levels.

The following waste percentages were included in calculating the New Zealand totals: ready mix (for all strengths) +1.1%; double tee beams + 0.5%; hollow core + 0.5%; blocks + 0.5%; and mortar + 1.1%. As a result of incorporating these waste percentages and rounding errors, Table totals may not add up exactly for the New Zealand figures.

Table 12: Comparison of emissions to air for low strength concrete production.

Atmospheric Emissions due to 17.5 MPa Ready-Mixed Concrete Production (grams/m^3)

	CO_2		VOCs		CO		CH_4		NOx		SO_2		TPM	
BY STAGE	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can	NZ	Can.
Extraction	5001	3690	6.1	4.5	31.3	23.1	1.5	1.1	57.1	42.1	7.4	5.3	47.8	96.7
Transport.	2641	4770	4.0	5.9	16.0	29.9	1.0	1.5	29	54.5	3.9	6.9	0.0	0.0
Manufact.	9165	15207	10.8	12.7	55.3	65.5	3.2	3.2	101.5	122.0	13.1	19.8	120.0	120.0
Cement	199364	156896	38.0	4.6	80.0	68.4	1.0	1.7	382.6	349.7	34.2	27.8	361.8	225.6
TOTAL	*218549*	*180563*	*59.5*	*27.7*	*184.6*	*186.9*	*6.8*	*7.5*	*576.5*	*568.3*	*59.2*	*59.8*	*535.4*	*442.3*

Table 13: Comparison of emissions to air for medium strength ready-mix concrete production.

Atmospheric Emissions due to 30 MPa Ready-Mixed Concrete Production (grams/m^3)

	CO_2		VOCs		CO		CH_4		NOx		SO_2		TPM	
BY STAGE	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can	NZ	Can.
Extraction	5206	3462.7	6.4	4.3	32.6	21.7	1.6	1.1	59.4	36.5	7.7	5.0	49.8	90.7
Transport.	2206	4638.6	4.0	5.7	13.0	29.1	1.0	1.4	23.0	53.0	3.0	6.7	0.0	0.0
Manufact.	9426	15345.6	11.1	12.8	56.9	66.1	3.3	3.2	104.4	123.1	13.5	19.9	120	120.0
Cement	261176	26040.9	49.8	12.6	104.8	114.2	1.2	2.8	501.3	584.1	44.9	46.5	474.0	376.8
TOTAL	*281072*	*49487.8*	*72.1*	*35.4*	*209.6*	*231.1*	*7.2*	*8.5*	*695.7*	*796.7*	*69.9*	*78.1*	*650.9*	*587.5*

Table 14: Emissions to air for high strength ready-mix concrete production (no comparison with Canadian figures possible).

Atmospheric Emissions due to 40 MPa Ready-Mixed Concrete Production (grams/m^3)

	CO_2		VOCs		CO		CH_4		NOx		SO_2		TPM	
BY STAGE	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can	NZ	Can.
Extraction	5367.8	-	6.6	-	33.6	-	1.6	-	61.3	-	7.9	-	51.3	-
Transport.	2254.0	-	4.0	-	13	-	1.0	-	23.0	-	3.0	-	0.0	-
Manufact.	9702.9	-	11.4	-	58.5	-	3.4	-	107.5	-	13.8	-	120.0	-
Cement	331693	-	63.3	-	133.1	-	1.6	-	636.6	-	57.4	-	602.0	-
TOTAL	*352857*	-	*86.2*	-	*240.8*	-	*7.7*	-	*837.5*	-	*83.0*	-	*781.8*	-

Table 15: Comparison of atmospheric emissions for double tee beam production.

Atmospheric Emissions due to double tee beam Production
(grams/lineal metre of Double Tee)

	CO_2		VOCs		CO		CH_4		NOx		SO_2		TPM	
BY STAGE	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can	NZ	Can.
TOTAL	*97 657*	*131 654*	*24*	*10.5*	*61.0*	*77.7*	*2.0*	*2.5*	*233*	*321.4*	*23.0*	*27.1*	-	*235.0*

Table 16: Comparative study of atmospheric emissions for hollow core construction.

Atmospheric Emissions due to Hollow Core Production
(grams/lineal metre of hollow core)

	CO_2		VOCs		CO		CH_4		NOx		SO_2		TPM	
BY STAGE	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can	NZ	Can.
TOTAL	*66 451*	*75 384*	*16*	*6.0*	*41.0*	*44.5*	*2*	*1.5*	*157*	*184.1*	*15.5*	*15.5*	-	*134.5*

Table 17: Comparison of emissions to air for concrete block production.

Atmospheric Emissions due to Concrete Block Production
(grams/block)

	CO_2		VOCs		CO		CH_4		NOx		SO_2		TPM	
BY STAGE	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can	NZ	Can.
Extraction	1.5	31.2	0.0	0.04	0.0	0.20	0.0	0.01	0.0	0.36	0.0	0.05	0.3	0.82
Transport.	21.8	36.8	0.0	0.05	0.1	0.23	0.0	0.01	0.2	0.42	0.0	0.05	0.0	0.0
Manufact.	141.1	606.9	0.2	0.22	0.8	1.18	0.1	0.06	1.5	2.44	0.2	0.24	0.9	1.15
Cement	1024.2	1492.8	0.2	0.07	0.4	0.65	0.0	0.02	2.0	3.33	0.2	0.26	1.9	2.15
TOTAL	*1194.5*	*2167.7*	*0.4*	*0.38*	*1.3*	*2.26*	*0.1*	*0.10*	*3.7*	*6.55*	*0.4*	*0.60*	*3.1*	*4.12*

Table 18: Comparison of atmospheric emissions for cement mortar production.

Atmospheric Emissions due to Cement Mortar Production
(grams/m^3)

	CO_2		VOCs		CO		CH_4		NOx		SO_2		TPM	
BY STAGE	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can.	NZ	Can	NZ	Can.
Extraction	508	1498.5	0.6	1.8	3.2	9.4	0.2	0.5	5.8	17.1	0.8	2.2	4.9	39.3
Transport.	2501	1964.7	4.0	2.4	15.0	12.3	1.0	0.6	26.0	22.4	3.7	2.8	0.0	0.0
Manufact.	445	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.2	0.0	15.4	0.0	120	120.0
Cement	334300	252184	64.0	12.1	134	109.9	2.0	2.7	642.0	562.1	57.0	44.8	607	362.7
TOTAL	*341469*	*255647*	*69.4*	*16.3*	*154.0*	*131.6*	*3.3*	*3.8*	*681.4*	*601.6*	*77.7*	*49.8*	*740.0*	*522.0*

9.1.1 Atmospheric pollutant summary

From Table 12 through to Table 18, it can be seen that for each of the concrete products, there is a close correspondence between the two countries' results. The generally greater production of pollutants in the New Zealand case is largely due to the greater cement manufacturing requirements, and is reflective of old technology (in the form of wet process kilns). Also, there is generally more reliance on the use of less polluting fuels in Canada, with more emphasis on the use of natural gas, which has lower sulphur dioxide, carbon monoxide, volatile organic compounds and nitrogen oxide emission rates per unit of energy delivered.

9.2 Energy Use

The following tables detail the energy use by product and stage.

Table 19: Comparative energy use in 17.5 MPa ready-mix concrete production: by process stage.

	Energy Use in 17.5 MPa Concrete Production	
Energy Use	**New Zealand (GJ/m^3)**	**Canada (GJ/m^3)**
Extraction	0.0707	0.0961
Transportation	0.0325	0.0675
Cement	1.0350	0.8956
Manufacturing	0.1616	0.2395
Total	***1.2998***	***1.2987***

Table 20: Comparative energy use in 30 MPa ready-mix concrete production: by process stage.

	Energy Use in 30 MPa Concrete Production	
Energy Use	**New Zealand (GJ/m^3)**	**Canada (GJ/m^3)**
Extraction	0.0736	0.0878
Transportation	0.0276	0.0685
Cement	1.3550	1.4958
Manufacturing	0.1662	0.2417
Total	***1.6224***	***1.8938***

Table 21: Comparative energy use in 40 MPa ready-mix concrete production: by process stage.

Energy Use	Energy Use in 40 MPa Concrete Production New Zealand (GJ/m^3)	 Canada (GJ/m^3)
Extraction	0.0759	-
Transportation	0.0285	-
Cement	1.7210	-
Manufacturing	0.1711	-
Total	***1.9965***	-

Table 22: Comparative energy use in double tee manufacture: by process stage.

	Energy Use in Double Tee Manufacture	
Energy Use	New Zealand (GJ/lineal metre)	Canada (GJ/lineal metre)
Extraction	0.0191	0.0215
Transportation	0.0095	0.0179
Cement	0.4736	0.7031
Manufacturing	0.1604*	0.1448*
Total	***0.6626***	***0.8873***

**includes embodied energy associated with the manufacture of steel*

Table 23: Comparative energy use in hollow core manufacture: by process stage.

	Energy Use in Hollow Core Manufacture	
Energy Use	New Zealand (GJ/lineal metre)	Canada (GJ/lineal metre)
Extraction	0.0127	0.0123
Transportation	0.0061	0.0103
Cement	0.3241	0.4026
Manufacturing	0.0975*	0.0829*
Total	***0.4404***	***0.5081***

**includes embodied energy associated with the manufacture of steel*

Table 24: Comparative energy use in concrete block production: by process stage.

	Energy Use in Concrete Block Production	
Energy Use	**New Zealand (GJ/block)**	**Canada (GJ/block)**
Extraction	0.00000	0.00087
Transportation	0.00031	0.00052
Cement	0.00531	0.00852
Manufacturing	0.00967	0.01241
Total	*0.01529*	*0.02232*

Table 25: Comparative energy use in cement mortar production: by process stage.

	Energy Use in Cement Mortar Production	
Energy Use	**New Zealand (GJ/m^3)**	**Canada (GJ/m^3)**
Extraction	0.0072	0.0466
Transportation	0.0338	0.0278
Cement	1.7350	1.4396
Manufacturing	0.0040	0.0040
Total	*1.780*	*1.5179*

9.2.1 Energy use summary

Overall, there is a close correspondence between the two nations' figures. However, the larger variances are mainly due to:

a. differences in energy accounting (e.g. for concrete block, the treatment of special 'blended' type of aggregate used in the mix design)

b. differences in the physical volumes of concrete products (e.g. the larger size of a standard whole Canadian concrete block, and the differing specifications of the precast products)

c. differences in mix design (e.g. the New Zealand hollow core has 15% less cement, which is the most energy intensive 'raw' material by far).

9.3 Water Use

Table 26: Estimated water use in the ready-mix industry – a NZ-Canadian comparison.

Estimated Water Use in the Ready-mix Concrete Industry		
Category	**New Zealand ($litre/m^3$)**	**Canada ($litre/m^3$)**
Batch Water	100	139 – 188
Truck Wash-Off*	8	15 – 317
Truck Washout*	8	5 – 69
Miscellaneous	60	15 – 129
Total	***176***	***174 - 703***

Note: *New Zealand truck washout and truck wash-off water figures were combined, so a simple 50/50 split between the two was made.

9.3.1 Water use summary

From Table 26 it can be seen that the New Zealand water usage rates are among the lower of those (estimated to be) used in Canada. It is unknown why New Zealand has considerably lower figures for some water types. Further investigation is necessary to answer this.

10. CONCLUSIONS AND RECOMMENDATIONS

This preliminary study investigated concrete-related environmental inputs and outputs during raw material extraction, transportation to plant and manufacture, for the New Zealand case. Seven concrete products were investigated – 17.5 MPa, 30 MPa, and 40 MPa ready-mix concrete, double tee and hollow core precast units, and concrete block and mortar. The methodology used was based on a Canadian study conducted in 1993.

10.1 Conclusions

Due to the nature of the information gained for this study, the conclusions should be regarded tentatively. There are several reasons for this:

- the sampled plants may not necessarily be representative of the industry, due to statistical methods not being applied
- a focus on the more efficient side of the industry, i.e. those that use central mixers
- the complexity of any life-cycling analysis-type study, and the preliminary nature of this study.

There is a lack of New Zealand environmental-related data associated with aspects of the raw material extraction, transportation and manufacture of concrete. Specifically, there is a lack of data on:

1. contaminated waste water (e.g. effluents such as: suspended solids, oil and grease, toxicity, aluminium, chlorides and sulphates) and water use
2. atmospheric pollution mitigation technology for stacks and flues, used in the production of cement
3. solid wastes (wet-concrete) from truck washout and wash-off
4. solid wastes from precast units and masonry block, compared to central-mix ready-mixed concrete.

Comparison of the New Zealand inventory data (circa 1999) with the Canadian inventory data (pre-1993) was fraught with difficulty. The reasons for this include:

- the studies were conducted nearly a decade apart, which has implications for technology, energy efficiency and pollutants
- the precast and block units have differing volumetric dimensions, thus resulting in non-uniform 'unit factors'
- the mix designs for each of the products are significantly different.

As a consequence of this, only a tentative comparison can be made between New Zealand-made concrete and Canadian-made concrete. However, it seems that:

For Atmospheric Emissions - there is a close correspondence between the two countries.

For Energy Use - there is a close correspondence between the two countries.

For Water Use - New Zealand usage rates are at the lower end of those estimated to be used in Canada.

For Effluent Generation - No comparison was possible, due to the lack of New Zealand figures available.

10.2 Recommendations

If this preliminary study is to be expanded upon, further investigation should be performed in the following areas:

1. a more representative (i.e. statistically-based) study of the pre-cast and ready mix industries
2. investigation into whether concrete admixtures used in most concrete mix are a significant environmental burden
3. sampling of a number of plants' liquid effluents, to provide some details of typical pollutants generated
4. a comparison of the solid wastes produced in the precast industry, with that of the ready-mix industry
5. investigation into whether the solid waste production estimate (which includes over-specification, off-specification and mixing residue) is actually representative of reality.

If any of the above investigations are to be conducted, they will be heavily reliant on the participation of individual plants for background information and monitoring.

APPENDIX A: LETTER SENT TO READY-MIX PLANTS

Dear <Plant Engineer>

RE: READY-MIX RESOURCE USE

As discussed on the phone, I am a researcher from BRANZ looking at the resource use 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.

The objective of this study is to gain estimates for all the inputs (e.g. raw material requirements, energy use, demand for water) and the outputs (e.g. solid and liquid wastes) for a given unit of structural (ready-mix) concrete. The project boundaries include raw material extraction through to final production in the plant. Several centrally-batched ready-mix plants will be examined, with their figures amalgamated to give an indication of the industry average. Because of this amalgamation, confidentiality of the plants will be ensured.

This resource study on ready-mix concrete will be non-judgemental and non-comparative - thus it will not rate one building material against another. Ultimately the information will be used in conjunction with building design data, maintenance, durability information and economic considerations to get a better picture of a buildings material's resource use.

I recognise that there may be sensitive resource-use information, however, I was hoping you would fill in the following tables and questions:

1. **Typical mix designs for 17.5 MPa, 30 MPa, and 40 MPa concrete:**

	Ready-mixed Concrete Strength		
Material	**17.5 MPa**	**30 MPa**	**40 MPa**
Cement (OPC/GP)			
Sand			
12 mm aggregate			
20 mm aggregate			
Water			

2. **The sources of your raw materials (i.e. location) and main mode of transport:**

Material	**Town**	**Truck/Rail/Ship**
Cement (OPC/GP)		
Sand		
12 mm aggregate		
20 mm aggregate		

3. Water usage and recycling in normal ready-mix operations:

A. How much town supply water do you use per month or per year for all your ready-mix operations (volume)?

B. How much storm water (i.e. rainwater runoff) do you use per month or per year (volume)?

C. Do you practice on-site recycling of water?

D. What percentage approximately is used on site?

E. Is your plant intending to recycle more water in the future?

4. Solid wastes and treatment:

A. What percentage of the mixes are wasted in:

- mixer washout residue
- off spec product
- returned excess in the trucks.

B. What is done with the waste concrete for each of these waste types?

5. Energy use:

[I would like to estimate what the energy usage is per tonne (or cubic metre) of concrete.]

A. How much electricity is used on site (per year or month)?

B. How much diesel is used on site, excluding that used in the trucks but including that used for earth-moving machinery?

6. Overall production estimate:

Approximately how many tonnes of ready-mixed concrete is made on site?

I am aware that your ready-mix plant is in a continual process of improvement, regarding use of resources - especially energy efficiency. However, at present, I am more concerned with getting a "snapshot" of current practice.

If you have any questions, you can either contact me at BRANZ ph 04 235 7600, or email me on **"branzraj@branz.org.nz"**. If you feel that it would be quicker to go through the questions by phone, please ring me. I would be very grateful if you could respond over the next three weeks.

Thank you for your help.

Yours sincerely

Roman Jaques
Building Technologist

APPENDIX B: TRANSPORT-RELATED EMBODIED ENERGY

Table 27 disaggregates the raw materials transportation-related embodied energy for each of the seven concrete mix designs. The different modes of transport (and their associated energy use) were accounted for by applying the following combustion energy factors from Forintek (1993):

MODE	FUEL	ENERGY REQUIRED (MJ/tonne- kilometre)
Truck	diesel (road)	1.18
Rail	diesel (rail)	0.49
Ship	marine	0.12

Where output was given in tonnes per year, conversion into cubic metres was performed based on the density of concrete being between 2.1 and 2.4 t/m^3.

Table 27: Breakdown of raw material transportation embodied energy.

TRANSPORTATION OF RAW MATERIALS FROM EXTRACTION TO PLANT						
Raw Material *(fuel)*	***Concrete Product***					
	17.5 MPa (GJ/t)	**30 MPa (GJ/t)**	**40 MPa (GJ/t)**	**Precast (GJ/t)**	**Mortar (GJ/t)**	**Block (GJ/t)**
Coarse Aggregate (diesel)	0.0105	0.0102	0.0100	0.0100	0.0102	0.0102
Fine Aggregate (diesel)	0.0031	0.0029	0.0030	0.0030	0.0030	0.0030
Sand (diesel)	0.0238	0.0171	0.0156	0.0156	0.0189	0.0189
Cement (heavy fuel oil)	0.0039	0.0050	0.0062	0.0062	0.0050	0.0050
Cement (diesel)	0.0090	0.0112	0.0138	0.0138	0.0113	0.0113

APPENDIX C: FUEL-RELATED ENERGY EMISSION FACTORS

Table 28: Fuel related energy emission factors (after EMR, 1990).

FUEL TYPE	CO_2	VOCs	CH_4	NO_x	CO	SO_2
	Kg / GJ	*Kg / TJ*	*Kg / TJ*	*Kg / TJ*	*Kg / TJ*	*Kg / TJ*
Petroleum	68	434	43	321	3805	11.7
Diesel (road)	70.7	86.9	21.7	807	443	0
Diesel (rail)	70.7	70	7.8	1400	443	0
Diesel (marine)	70.7	390	45	240	180	0
Heavy Fuel Oil (Marine)	74	360	40	200	7.4	450

APPENDIX D: REBAR TRANSPORTATION ENERGY

Reinforcing steel is transported from the steel manufacturing plant to the precast manufacturer. To find the transportation-related embodied energy figure for the reinforcing bar used in the precast products, the following procedure was adopted.

STEPS

1. Find out the distribution of precast operators around the country (major operators only).
2. Find the main modes of transportation for the rebar, for each of these precast operators.
3. Assume that the amount of precast products made is proportional to the building activity for each city. (Regional figures of precast output were not available, so building activity is based on the annual costs of consents).
4. Calculate the rebar transportation distances (from Pacific Steel in Auckland to the precast operator).
5. Proportion the transportation embodied energy intensity according to the regional output, then find the average for the whole of New Zealand.

Region	Location	Distance travelled (km)	Return distance (km)	Main transport mode	Mode intensity (MJ/t-km)	Gross figure MJ/t	Regional ratio	Embodied energy MJ/t
Wellington	Otaki	560	1120	train	0.49			
	Otaki	560	1120	train	0.49			
	Lower Hutt	590	1180	train	0.49			
Av Wgtn			**1140**		***0.49***	***558.6***	***x***	***x***
Auckland	Whangarei	170	340	train	0.49			
	Auckland	5	10	truck	1.18			
	Rotorua	200	400	train	0.49			
	Orewa	40	80	truck	1.18			
	Henderson	15	30	truck	1.18			
	Mt Wellington	5	10	truck	1.18			
	Beachlands	40	80	truck	1.18			
Av Akld			**136**		**1.0**	**133.4**	**x**	**x**
Hamilton	Hamilton	100	200	train	0.49			
Av Ham			**200**	**train**	**0.49**	**98**	**x**	**x**
Palmerston Nth	P Nth	410	820	train	0.49			
Av PNth			**820**	**train**	**0.49**	**401.8**	**x**	**x**
Dunedin	Dunedin	880	1760	ship	0.12			
		370	740	train	0.49			
	Dunedin	880	1760	ship	0.12			
		370	740	train	0.49			
Av Dunedin			**1250**		**0.305**	**381.3**	**x**	**x**
Christchurch	Christchurch	880	1760	ship	0.12			
	Christchurch	*880*	*1760*	*ship*	*0.12*			
Av Chch			**1760**		**0.12**	**211.2**	**x**	**x**

Table 29: Transportation-related embodied energy for New Zealand rebars for precast construction.

x = information withheld for confidentiality reasons.

Table 29 can then be condensed into:

Table 30: Condensed transportation related embodied energy for rebar.

TRANSPORTATION-RELATED EMBODIED ENERGY FOR REINFORCING STEEL			
Transport Mode	**Weighted Av Distance (km)**	**Transport Energy (MJ/t-km)**	**Embodied Energy (MJ/kg)**
Truck	10	1.18	0.0120
Train	474	0.49	0.2321
Ship	164	0.12	0.0197

The total New Zealand transportation embodied energy for reinforcing steel equates to 0.264 MJ/kg (compared with the Canadian figure of 0.408 MJ/kg). This is reflective of the much larger average distances covered by Canadian reinforcing steel to get it to their respective regional plants.

Reinforcing steel transportation related emissions to air are found by multiplying the energy used by mode (Table 30) by the fuel-related emissions (Table 31) to get:

Table 31: Transport-related atmospheric emissions for reinforcing steel used in precast products.

Atmospheric Emissions due to Transportation of Reinforcing Steel (kg of pollutant / tonne of rebar)							
Mode	**CO_2**	**VOCs**	**CO**	**CH_4**	**NOx**	**SO_2**	**TPM**
Truck	0.847	0.001	0.0	0.000	0.010	0.001	-
Train	16.408	0.016	0.002	0.002	0.325	0.024	-
Ship	1.394	0.008	0.001	0.001	0.005	0.002	-
TOTAL	**18.649**	**0.025**	**0.003**	**0.003**	**0.339**	**0.028**	**-**

APPENDIX E: A NOTE ON ADMIXTURES

Admixtures used in concrete mix design include water reducers (to increase the workability), accelerators (to promote early strength gains) and retarders (to delay the initial setting time). The exact effect of admixtures is dependent on dosage, mix proportions and temperature. The most common admixtures to be used in concrete are normal water reducing and super plasticisers (Chisholm, 1999). The type and amount of admixture used varies between plants, but is typically very small - around 0.1kg per cubic metre of lower strength concrete (i.e. less than 0.01%). These admixtures are generally lingosulphonates (Campbell, 2000).

Under Forintek's research guidelines (1993 and 1993a), admixtures are classified as an 'ancillary material'. An ancillary material is one which does not appear to be a major contributor to the product being assessed. The general convention for ancillary materials is that if it makes up more than 2% or more of inputs (by mass) to a process, it should be accounted for. However, there is the exception to this, which reads: "*Furthermore any material, no matter how small it's mass contribution, which has extraordinary effects in its extraction, use or disposal...should be accounted for if it is an integral part of the product or essential to its production*".

Accounting for concrete admixtures is difficult however, mainly for two reasons:

(a) admixture chemical composition can vary greatly. For example, super plasticisers may have any of the following principal chemicals - sulphonated melamine formaldehyde condensates, sulphonated naphthalene formaldehyde condensates, and modified lignosulphonates (from NZCRA, 1986)

(b) the confidentiality that surrounds a plant's mix design. The plants investigated were very wary of giving any information on their use of admixtures (whether quantity applied or type used), and therefore little information could be derived.

Thus, this study was unable to determine whether the admixtures used have 'extraordinary effects'. This issue could be further explored in future studies.

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Moonshine Road, Judgeford
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Telephone – (04) 235-7600, Fax – (04) 235-6070
Internet – http:/ / www.branz.org.nz
E-mail – postmaster@branz.co.nz

NEW ZEALAND OFFICES

AUCKLAND

Telephone – (09) 303-4902
Fax – (09) 303-4903
The Building Technology Centre
Victoria Park, 17 Drake Street
PO Box 90524, Auckland Mail Centre

CHRISTCHURCH

Telephone – (03) 366-3435
Fax – (09) 366-8552
GRE Building
79-83 Hereford Street
PO Box 496

AUSTRALIAN OFFICE

Telephone – (00612) 8339 1881
Fax – (00612) 8339 1884
Unit 32, 56 O'Riordan Street
Alexandria, NSW 1460, Australia
PO Box 323, Mascot, NSW 1460