BACK TO AGENDA

SCM's potential to lower Australia's greenhouse gas emissions profile

Craig Heidrich[1], Dr Ihor Hinczak[2], Bridget Ryan[3]

[1]HBM Group Pty Ltd, PO BOX 1194, Wollongong, NSW 2500, Australia, [2]Cementech Pty Ltd PO BOX 362, Liverpool NSW 2170 [3]Energy Supply Association of Australia, GPO Box 1823Q Melbourne Vic 3001

KEYWORDS: greenhouse gas emissions, cement, concrete, fly ash, iron blast furnace slag, supplementary cementitious material.

ABSTRACT

Under the Kyoto Accounting rules, Australia's National Greenhouse Gas Inventory Report emissions for 2002 was 550.1 Mt carbon dioxide equivalent (CO_2-e) being a net increase of 1.3% on the 1990 level. This increase is largely attributed to the stationary energy, transport and industrial process sectors, offset with significant reductions from reduced land clearing.

For the construction sector additional mitigation strategies could be employed to further reduce Australia's net CO_2-e emissions. For example through increased use of mineral resources like coal combustion products such as; fly ash, iron blast furnace slag and amorphous silica, or commonly referred to as supplementary cementitious materials (SCM's), used with Portland cement in the manufacture of concrete. For Australia, the manufacture and delivery of one tonne of cement results in the emission of approximately 0.82 tonne of CO_2-e or 6.5 Mt of CO_2-e emitted for total cement sales in 2002.

Using data collected from companies processing fly ash and iron blast furnace slag, life cycle analyses were conducted to demonstrate the reduced embodied energy and resultant CO_2-e signature for one cubic meter of concrete containing various combinations of fly ash and iron blast furnace slag. From the resultant data and analysis a simple CO_2-e estimator has been developed to assist architects, designers and consulting engineers to specify eco-friendly structures.

For the construction of a domestic dwelling (four bedroom home) using approximately 130 cubic meters (m3) of 25 MPa concrete containing binder ratios of 35% Portland cement and 65% ground granulated blast furnace slag cement, the total savings in CO_2-e emissions was 17.03 tonnes, or equivalent to emissions from a four-cylinder car for 5.68 years.

The paper will briefly discuss Australia's current National Greenhouse Gas Inventory Report in the context of how increased use of SCM's in the construction sector can further lower greenhouse gas emissions, whilst still delivering improved durability performance.

INTRODUCTION

More than seven years after its inception, the Kyoto Protocol[1] came into effect on February 16, 2005, and those countries who have ratified must now make good their promise to cut greenhouse-gas emissions [1]. The Protocol adopted in December 1997, could not be enforced until it had been ratified by a set of industrialised countries that in 1990, were responsible for at least 55 per cent of global greenhouse gas (GHG) emissions [2]. That threshold was reached by the Russian ratification of the Protocol in November 2004, which set in motion a 90-day countdown until the protocol could become law in 2005.

Australia's national government is a signatory to the Kyoto Protocol, but has said it will not ratify the instrument as it maintains that the ratification of the Protocol is not in the national interest. Minister for the Environment, Senator Ian Campbell [3] reaffirmed the national governments long held position… *Australia will continue to work hard in various forums to get all of the world's major emitting countries - not only some of them - to commit to a new treaty beyond Kyoto that will achieve the deep cuts that scientists agree are required to stabilise the concentrations of carbon dioxide in the atmosphere*. This position for Australia's national government has been unwavering since the Protocol's inception back in 1997.

Although the national government position is clear with regard to ratifying the Kyoto Protocol, within the Ministers statement Australia again acknowledges the broader climate change debate, its continued development and traction it is gaining internationally, evidenced by the entry into force of the Protocol. Australia's position and focus is rather emphatically on the post 2012 negotiations, with the view to ensuring the development of a workable international frame-work that all countries can subscribe to without undermining national interests or economic growth opportunities.

Other longer-term Australian observers, that is scientists and economists, hold similar views of the Kyoto Protocol, and fit with Australia's interests, for differing reasons. Economist Warrick McKibbon[2] (2005) argues that the Kyoto Protocol is flawed in many ways. Fundamentally the agreement provides no cost certainty or property rights to negotiate on carbon emitted by industry [4]. This uncertainty results in the delay of future capital investments, which arguably are needed for continued economic development and growth of industry. McKibbon further argues that the Protocol ultimately establishes mechanisms for significant wealth transfers between countries which have large endowments of natural resources containing carbon – this is the case for Australia, and accordingly is not in its national interests.

---

[1] United Nations Framework Convention on Climate Change (UNFCCC) negotiated a convention in 1997 called the Kyoto Protocol. The major feature of the convention included the establishment of mandatory targets on greenhouse-gas emissions for the world's leading economies which have accepted it. Targets range from -8 per cent to +10 per cent of the countries' individual 1990 emissions levels "with a view to reducing their overall emissions of such gases by at least 5 per cent below existing 1990 levels in the commitment period 2008 to 2012.

[2] Professor Warwick McKibbin is Professorial Fellow at the Lowy Institute for International Policy. He is also Professor of International Economics and Convenor of the Economics Division in the Research School of Pacific and Asian Studies at the Australian National University and a nonresident Senior Fellow at the Brookings Institution in Washington, DC.

Now that the Kyoto Protocol has entered into force, debate continues within domestic and international circles over Australia's potential ratification of the Protocol. As discussed previously (Campbell 2005; McKibbin 2005) a number of well regarded economists and government officials suggest the main game now is looking beyond Kyoto and 2012. Irrespective of the national governments stated position on signing the Protocol, the government continues to work towards the Protocols agreed target. In particular national programmes have been designed to target both mitigation[3] and adaptation[4] strategies as part of a sensible climate policy approach.

The national government has positioned itself at the vanguard by establishing various programs designed to address climate change. For example the National Climate Change Adaptation Programme is a $14.2 million programme, which aims to commence preparing Australian governments and vulnerable industries and communities for the unavoidable impacts of climate change [5]. Other programmes such as the Alternative Fuels Conversion Programme, Cities for Climate Protection, Greenhouse Action in Regional Australia, Greenhouse Gas Abatement Programme and Renewable energy – all represent a significant commitment of public fiscal resources [6] to address future climate change.

From these programmes, the resultant strategies to address climate change will need to be embraced at all levels of government (federal, state and local), industry sectors and by the community. McKibbon suggests the role for government could be to create an environment for individuals to take action on both mitigation and adaptation strategies through clear allocation and protection of property rights and clear restrictions on certain activities [4].

If we adopt a cautionary approach, that is the divide between optimistic and pessimistic, set the scientific, economic and political debates to one side, accept that climate change risk exists. National, state and local governments, industry sectors and householders need to work collaboratively, and consider seriously appropriate mitigation and adaptation strategies that can be best employed without any significant negative effect on national economic growth and development.

Projections from the Australian Greenhouse Office (AGO) based on the 2002 National Greenhouse Gas Inventory [7] suggest that, without introducing any further abatement measures, Australian emissions will average 110 percent over the Kyoto commitment period 2008 - 2012. So, the target is within sight, but more needs to be done.

---

[3] Actions to cut net emissions of greenhouse gases and so reduce climate change. Examples are using fossil fuels more efficiently for industrial processes or electricity generation, switching to solar energy or wind power, improving the insulation of buildings, and expanding forests and other "sinks" to remove greater amounts of carbon dioxide from the atmosphere.

[4] Actions taken to help communities and ecosystems cope with changing climate conditions, such as the construction of flood walls to protect property from stronger storms and heavier precipitation, or the planting of agricultural crops and trees more suited to warmer temperatures and drier soil conditions.

AUSTRALIAN GHG EMISSIONS WITHIN AN INTERNATIONAL CONTEXT

Under the Kyoto Accounting rules, Australia's National Greenhouse Gas Inventory Report emissions for 2002 was 550.1 Mt carbon dioxide equivalent (CO_2-e) being a net increase of 1.3 percent on the 1990 levels of 543.2 Mt. Under the accounting provisions of the UNFCCC[5], which are broader in scope than those of the Kyoto Protocol, Australia's net emissions increased by 2.2 percent in 2002 to 539.2 Mt. For the purposes of comparison, net emission, using UNFCCC accounting provisions in 1990 were 515.9 Mt [7, pg iv]. For this paper all references and calculations will be based on UNFCCC accounting provisions.

Figure 1 – *Total aggregate greenhouse gas emissions of individual Annex I parties 2002* shows Australia's net change in percentage terms relative the base line emission as at 1990. As outlined previously, this reported data places Australia on track to meeting its obligations of the 108 percent of 1990 base line year.

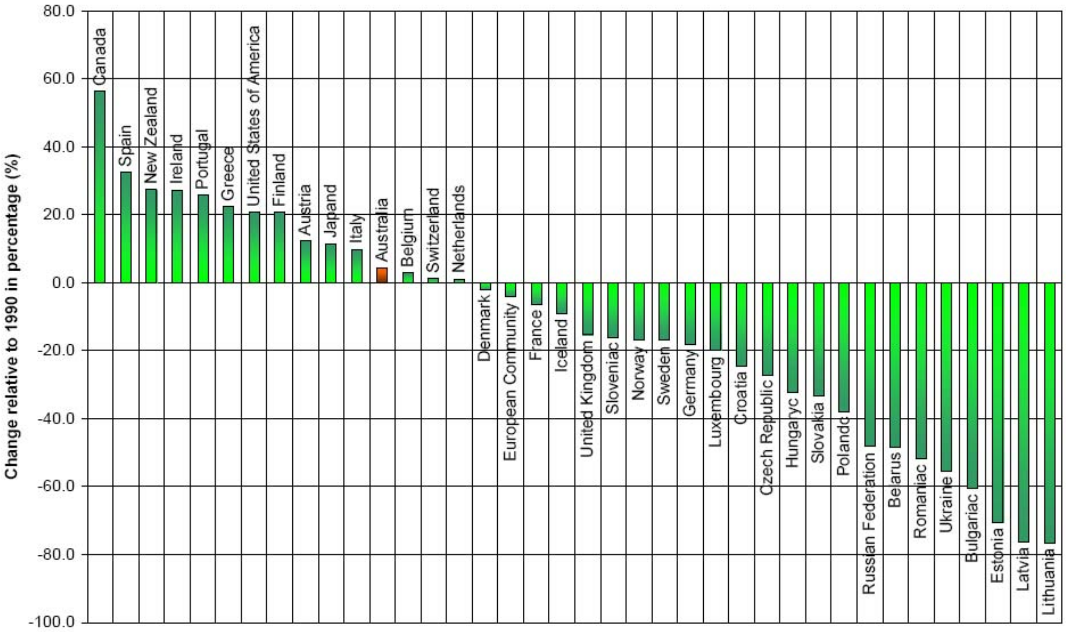


Figure 1 - Total aggregate greenhouse gas emissions of individual Annex I parties 2002 [8]

---

[5] The United Nations Framework Convention on Climate Change (UNFCCC) sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other heat-trapping gases.

Australia’s contribution to global greenhouse gas emissions for Annex I countries from all activities is 3.3 per cent. Australia’s greenhouse gas contribution could be considered insignificant when compared to countries like the USA and EU at 39 per cent and 25 per cent respectively. However it is noteworthy that based on an analysis of this data, on a per capita basis, Australia’s greenhouse gas emissions are more than double than that of the USA. This emissions intensity profile highlights Australia’s significant economic reliance on our large endowment of natural resources containing carbon.

Figure 2 – Selected Top Ten Annex I Countries by Emissions - adapted from data list on the UNFCCC websites provides a graphical representation of the top ten Annex I countries by emissions as at 2002 using the UNFCCC accounting provisions.

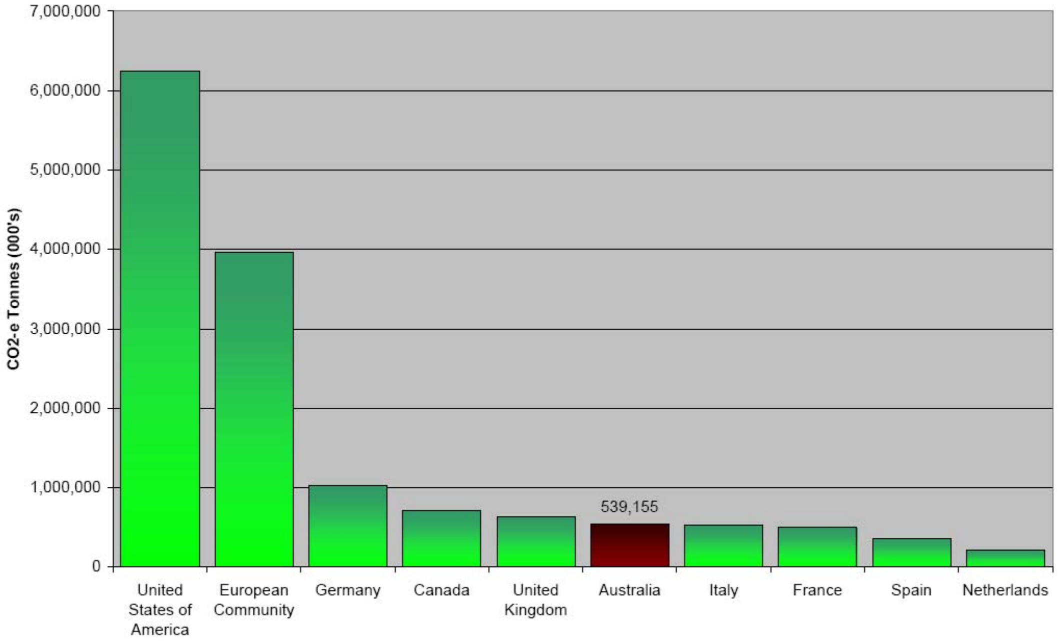


Figure 2 – Selected Top Ten Annex I Countries by Emissions - adapted from [9]

The NGGI reports Australia’s increases in CO_2-e have largely been attributed to the stationary energy, transport and industrial process sectors, offset with reductions from reduced land clearing [7, pg iv]. These sector increases and offsets have been recurring themes in NGGI reports since the early nineties.

Putting a particular focus on the sector report for land use change, it is arguable that the offsets from land use change are unsustainable in the medium term, given the significant reported reductions that have occurred since the 1990 base reporting year. *Figure 3 – Land use change emissions 1990 – 2002*.

In 1990 more than 85 Mt of CO_2-e was accounted for under land use change and forestry activities, whereas in 2002 this reported figure had reduced to less than 18.2 Mt of CO_2-e. Given an overall decline of almost 80 per cent, it can be argued that at this rate of reduction, average 5.5 Mt/annum, and with six years until 2008, there is limited scope for further reductions to be achieved from this sector. Moreover questions ultimately arise as to what additional mitigation strategies Australia can implement to maintain our continued reduction in net emissions.

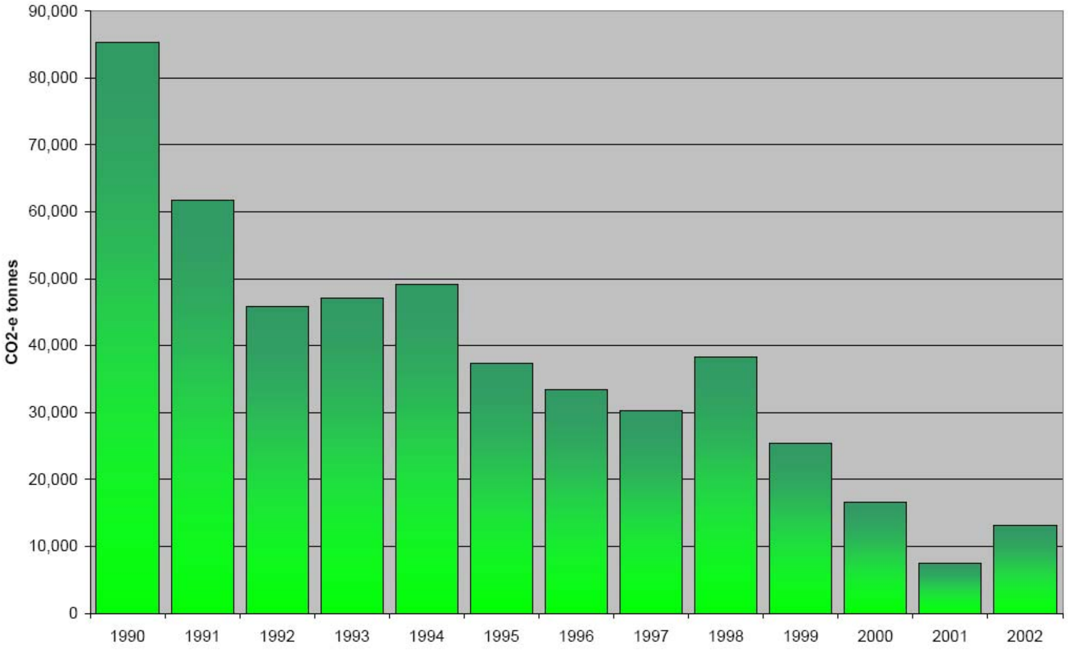


Figure 3 – Land use change emissions 1990 – 2002 [10]

Given the previous information, it could be concluded that limited further reductions are achievable from the land use change sector for Australia to achieve 108 percent by 2008. Accordingly an increased focus on sub-sector mitigation strategies must be placed on the agenda. Further 'low hanging fruit' for reductions within Australia's emission profile are limited going forward, as evidenced by the land use changes reductions. Other sectors such as industrial processes may afford some additional opportunities through the use of recovered mineral resources such as coal combustion products (CCP's) and various forms of iron blast furnace slag (BFS), which exhibits extremely low emission factors, and accordingly could be used to <u>displace</u> or <u>mitigate</u> Australia's growing greenhouse gas emissions profile.

The general literature on recovered resources, that is CCP's and BFS, reports increased use within the construction sector over the past 15 years. Use in cement and concrete manufacture would seem to be well understood technically and communicated to the broader user community [11-18]. Further the literature reports that both materials in various studies exhibit extremely low emission factors [19, 20] affording greater use opportunity for the construction sector. Based on this information further quantities could be used to <u>displace</u> or <u>mitigate</u> Australia's growing greenhouse gas emissions profile with limited requirement for additional investment or capital and impact on current infrastructure.

AUSTRALIAN SECTOR EMISSIONS

Australian net emissions are attributed to seven (7) sectors in the 2002 inventory. The largest contributor is the stationary energy sector comprising 47.6 per cent (261.9 Mt CO_2-e), next, agriculture at 19.2 per cent (105.6 Mt CO_2-e), transport at 14.4 per cent (79.2 Mt CO_2-e), fugitive emissions from fuel at 5.5 per cent (30.2 Mt CO_2-e), land use change and forestry at 5.3 per cent (29.2 Mt CO_2-e) industrial processes (including cement production) at 4.8 per cent (26.4 Mt CO_2-e) and waste at 3.2 per cent (17.6 Mt CO_2-e) [7, pg 11].

Focusing specifically on industrial processes, net emissions were 26.4 Mt CO_2-e in 2002 or 4.8 per cent of net total emissions for all sectors. For industrial processes, cement production is included in (A) Mineral Products and is reported in Table 2(I) Sectoral Report for Industrial Processes of the National Greenhouse Gas Inventory 2002 (NGGI), accounting for 3.3 Mt CO_2-e or 63 per cent of the sub-sector emissions.

INDUSTRIAL PROCESSES - CEMENT MANUFACTURING EMISSIONS

Total cement production for 2002 is reported to be 7.9 Mt [21]. An analysis of the emissions reported in the NGGI, divided by total cement production for 2002 equates to 0.417 t of CO_2-e /t of cement. This emission figure is significantly below that reported in much of the existing literature on net CO_2-e /t of cement produced for Australia. For example an international report commissioned by World Business Council for Sustainable Development (WBCSD) titled *Toward a Sustainable Cement Industry - Substudy 8: Climate Change 2002* [14] states… ‘Australia and New Zealand’s combined CO_2-e /t of cement manufactured is 0.79/t’. In a study conducted by BHP Minerals Technology titled *Case study: Cement production in Australia 2001* [22] the study concluded the weighted average impact [emissions] from cement production was 1.02 t of CO_2-e /t of cement.

The Cement Industry Federation (CIF) reported in the *Cement Industry Environment Report* [23], page 8 states…*in 1990, the Australian cement industry greenhouse gas emissions from fuel and process sources were 5.87 Mt of CO_2-e. The cement industry has achieved a reduction of fuel and process emissions to 5.45 Mt in 2002.* This reported figure 5.45 Mt of CO_2-e is 2.15 Mt greater than that reported figure in the NGGI 2002 [7, p 19].

Taking a closer look at specific data reported across the clinker and cement production sectors, combined with data from supplementary cementitious materials (SCM’s) producers, we can further segment the various contributions made by each activity. In *Table 1 - Australian industrial processes, subsector cement, 2002* data has been adapted from the following sources [21, 23-25].

Activity	**Mt**	**CO_2-e/tonne**
(a) Australian Clinker Production, 2002 (1)	6.6	0.83
(b) Australian Cement Production, 2002 (2)	7.9	0.69
Short fall or Net Difference (a-b = c)	**1.3**	**0.14**
(d) SCM use in cement production (3)	0.65	
(e) Clinker other sources (4)	0.65	
Cement Product reported Greenhouse gas emissions CO_2-e, 2002 (5)	5.45	

Notes:

(1) CIF 2003, Cement Industry Environment Report, Cement Industry Federation, Canberra, ACT.

(2) ABS 2003, MANUFACTURING PRODUCTION: 8301.0, Australian Bureau of Statistics, Canberra.

(3) CIF 2005, 'Supplementary Cementitious Materials: 2002', Available: http://www.cement.org.au/industry.htm [Accessed 2005, Jan 2005] including limestone, fly ash and iron slag

(4) Calculated net difference bewteen local production capacity combined with SCM use during milling process from reported cement production
(c-d= e)

(5) CIF 2003, Cement Industry Environment Report, Cement Industry Federation, Canberra, ACT. pg 8

Table 1 – Australian industrial processes, subsector cement, 2002

The CIF reports total clinker[6] production within Australia for 2002 was 6.6 Mt, with total cement[7] production 7.9 Mt [24]. The shortfall or net difference is 1.3 Mt and is reported as a combination of SCM's (limestone, fly ash and slag used in the milling process with clinker to manufacture cement) of 0.65 Mt [25]. The remaining shortfall is made up of unspecified sources; however it can reasonably be assumed this material is cement and clinker from other sources, most likely, imported.

Using the reported greenhouse gas emissions for 2002 at 5.45 Mt, this would equate to 0.83 CO_2-e /t for net Australian clinker production or 0.69 CO_2-e /t for net Australian cement production.

For the purposes of this case study, the paper will rely on the report by WBCSD [21] *Industry - Substudy 8: Climate Change 2002* and the reported CO_2-e /t of 0.79/t of cement manufactured, excluding transportation emissions for delivery.

Total concrete production for the calendar period 2003 exceed more than 21 million cubic meters [21].

CEMENT AND SCM's USE IN CONCRETE

In the previous discussion we established that 7.9 Mt of cement was manufactured using an estimated 0.65 Mt of SCM's in 2002 to supplement the manufacture of cement. That is, in the form of feedstock when manufacturing clinker, or inter-ground

---

[6] The artificial calcium silicate rock formed during the clinkerising process in the kiln and then ground finely to make cement CIF 2005d, 'Principles, Acronyms and Glossary', Available: http://www.cement.org.au/glossary.htm [Accessed 2005, Jan 2005].

[7] A calcium alumina silicate with hydraulic properties that enable it to act as glue binding other materials together and used in construction Ibid., Available: [Accessed 2005].

with clinker to manufacture cement. Although the use of SCM's as a feedstock in clinker manufacture is common-place in countries like Japan [26], the use of SCM's such as, fly ash and blast furnace slag to manufacture clinker in Australia is rare, which is mainly due to our abundant natural resources. The majority of SCM's use in Australia would be by way of inter-grinding during the conversion stage of clinker to cement.

Cement is the primary input material into the building and construction sector, as the binder or glue used to manufacture concrete[8]. Cement is sold in bulk, generally to downstream manufacturers [concrete plants], distributors [intermediaries] and end users [retail products].

Concrete is made in varying proportions from differing components arising from varied sources, and blended or mixed in different proportions subject to the specified end use. Typically the main components within one cubic meter of concrete by volume are, cement or binder 11 percent (Portland cement and SCM's), coarse aggregate 41 percent (gravel, crushed stone or slag), fine aggregate 26 percent (sand) water 16 percent and air 6 percent.

Total concrete production in Australia for the calendar period 2003 exceeded more than 21 million cubic meters [21], which used approximately 65 to 70 percent of the total cement production.

For the calendar period 2003 approximately 3.1 Mt (million tonnes) of iron and steel slag products were produced within Australasia (Australia and New Zealand). Based on current industry estimates, this volume is expected to increase at around 10 percent over the next 5 to 10 years. From the slag's produced, some 2.185 Mt or 69 percent can be said to have been effectively utilised. The main contributors, cementitious applications at 0.554 Mt, non cementitious applications at 1.631 Mt, with the balance of 0.915 Mt or remaining surplus stored onsite awaiting some future opportunity for economic reuse.

LIFE CYCLE ANALYSIS SCOPE

The scope of the study was to collect primary data from companies supplying various input materials [SCM's] and conduct life cycle analyses to illustrate CO_2-e emission for one cubic meter of concrete containing various combinations of iron blast furnace slag with other traditional binders, namely Portland cement.

The resultant data, formulae and concrete mix design options be incorporated into a simplified CO_2-e estimator for use by architects, designers and consulting engineers where they can input independent variables such as required cubic meters in concrete, target strength, and binder composition.

The resultant information [output data] can be used to assist architects, designers and consulting engineers in understanding the reduced greenhouse gas impact when specifying eco-friendly concrete structures using blended cements.

---

[8] In its simplest form, concrete is a mixture of [cement] paste and aggregates. The paste, composed of cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete. Available: http://www.aci.org

METHODOLOGY

The study required the collection of data from primary and secondary sources. Primary sources are individual supplementary cementitious materials (SCM) processing sites, and associated externalities (i.e. provision of raw materials, transport, fuels and electricity) from throughout Australia. Secondary data sources are associated energy, transport and materials inputs used to manufacture one (1) standard cubic meter in the published literature.

The methods and calculations for all greenhouse gas emissions are as specified in the AGO Factors and Method Workbook, Version 4 – August 2004 [27]. The system boundaries methodology is based on previous work by *BHP Minerals Technology, Case study: Cement production in Australia 2001* [22].

SYSTEM BOUNDARIES - PORTLAND CEMENT

The system boundary for the manufacture of one (1) tonne of Portland cement, includes the extraction of raw materials, transportation, provision of fuels and associated consumables (electricity, coal, limestone, mineral sands and clays etc), and emission from the clinkering and grinding process.

The following figure provides a flow chart for the manufacturing process for one (1) tonne of Portland cement ex works (from place of manufacture).

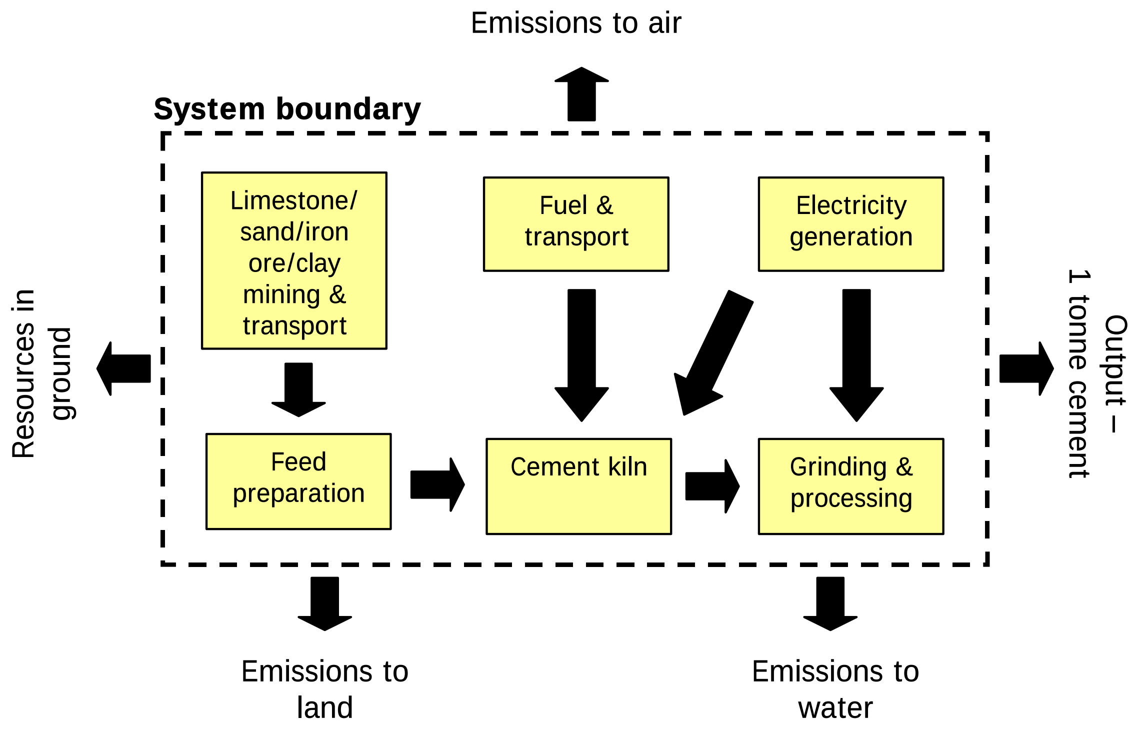


Figure 4– Main stages and process to manufacture one (1) tonne of Portland cement [22, 23]

GHG FROM CALCINATION (PROCESS EMISSIONS)

Cement is produced mainly from calcium, silica, iron and alumina bearing materials such as limestone, sandstone, iron ore and clay/shale [13]. The manufacture of cement firstly involves pyro-processing the raw materials to produce clinker. During this manufacturing reaction process called calcination CO_2 is released. This product [clinker] is then ground into a fine power with additions of gypsum and SCM's to produce cement.

For the purpose of this analysis the manufacture of one tonne of Portland cement results in the emission of 0.82 tonne of CO_2-e /tonne[9] of cement, including direct emissions resulting from the transportation of finished product ex works to premix concrete plant [14].

SYSTEM BOUNDARIES - GROUND GRANULATED IRON BLAST FURNACE SLAG (GGBFS)

The system boundary for the manufacture of one (1) tonne of GGBFS includes the collection, extraction, processing, provision of fuels and associated consumables (electricity, coal, gypsum etc) and transportation to a distance of 100 kilometers from the manufacturing/processing site.

The following figure shows the flow chart for the manufacturing process.

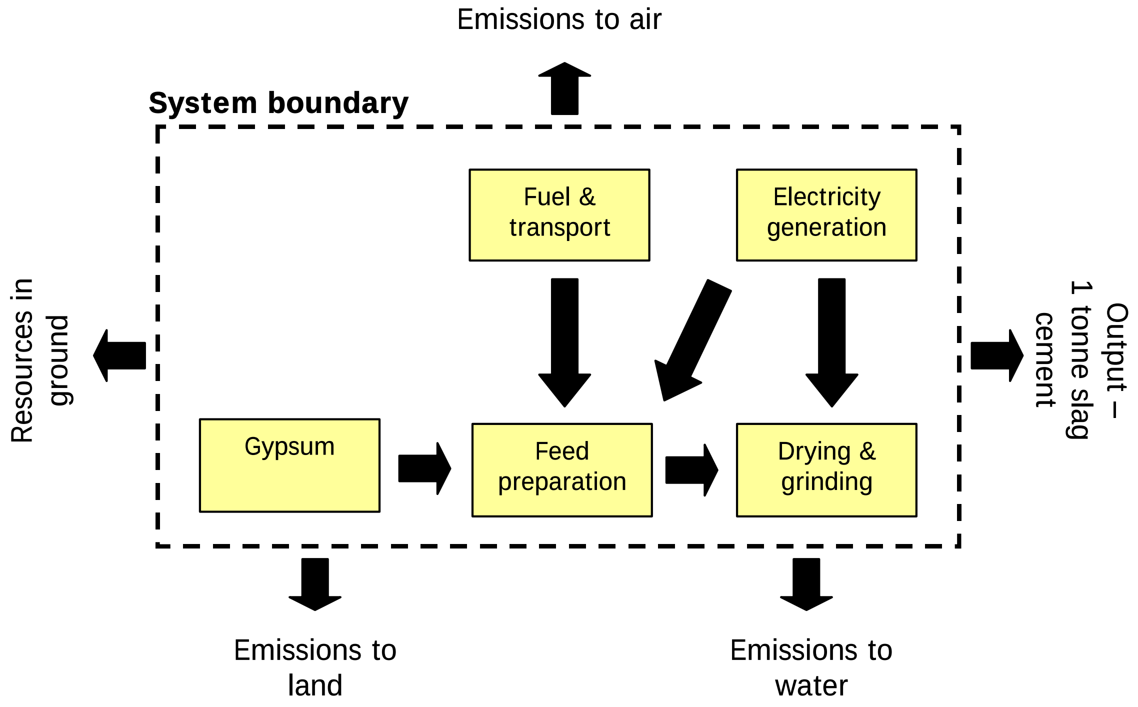


Figure 5 – Main stages and process to manufacture one (1) tonne GGBFS

GHG FROM RECOVERY OF GGBFS (PROCESS EMISSIONS)

---

[9] Australia and New Zealand's combined CO2-e /t of cement manufactured is 0.79/t as reported by World Business Council for Sustainable Development titled Toward a Sustainable Cement Industry - Substudy 8: Climate Change 2002. An additional direct emission of 0.04/t of cement manufactured added to ccount for emission for delivery up to 100 kilometers from manufacturing site.

Slag is a by-product of the iron and steel manufacturing process. The first step in the production of steel is to manufacture iron. Iron ore, a mixture of oxides of iron, silica and alumina, together with a fuel consisting of coke, natural gas, oxygen and pulverised coal and also limestone as a fluxing agent, are fed into a blast furnace which consists of a large vertical chamber through which large volumes of hot air are blasted. Generally a blast furnace operates on a continuous basis and produces approximately 250 — 300 kg of slag per tonne of iron produced.

The chemical reaction results in two products: molten iron metal and molten blast furnace slag. At this stage molten blast furnace slag can be converted into two different products; (1) blast furnace slag aggregate (BFS) or; (2) granulated blast furnace slag (GBFS). To produce GBFS, liquid slag must be rapidly quenched using large volumes of high-pressure fresh water sprays instantly cooling the molten material to produce a sandy material having a top size of 6 mm.

Typically GBFS is then collected from the manufacturing source, blast furnace granulation bays, and transported to nominated processing facilities. The GBFS [product] is then de-watered and dried to reduce the moister content before further processing [grinding] in a similar manner to that of cement clinker using traditional cement clinker grinding plant. At this point the ground granulated blast furnace slag or GGBFS [product] is stored in silos awaiting delivery to customers.

Using the collected data and emission factors, the calculated average energy inputs to, capture, process and distribute one tonne of GGBFS is shown in *Table 2 – Weighted average emission factors for one tonne of GGBFS*.

As shown in the table milling represents 44 percent of emissions, drying 24 percent and transport emissions making up the reminder of 21 percent.

GGBFS	**CO_2-e/t**	**%**
Milling, kWh/tonne	0.064	44.5%
Drying, GJ/m3 N. Gas	0.049	34.5%
Transport, litres fuel	0.020	14.2%
Transport, HFO, mts	0.010	6.9%
Total CO_2/tonne	**0.143**	**100.0%**

Table 2 – Weighted average emission factors for one tonne of GGBFS

There is limited literature documenting direct emissions fro the manufacture of GGBFS in Australia. The papers by Munn [19] and Potter [20] investigating emission data using average energy factors of 0.11 tonnes of CO2 per GJ of energy reported emission of 0.275t CO_2-e /t for one GGBFS processed and delivered. The papers provide no detailed break up of the individual energy input and associated weightings. It is our assumption these were at the time, best estimates.

Our study revealed these original estimates reported GGBFS having a factor two greater than our study results, that is, 0.143t CO_2-e /t for one GGBFS processed and delivered up to 100 kilometers from the manufacturing site.

Following the review of the contributions to greenhouse gases by cement and the results of the study of GGBFS, the use of these materials to manufacture one cubic meter of concrete is now examined.

For the purpose of the study input constituents and direct emissions factors for tonne of material used in varying combinations to produce one cubic meter of concrete will be based on the values in *Table 3 – Constituent emission factors*.

The values for coarse and fine aggregates have been adopted from the paper by Munn (1975) and working paper by Flower (2005) from Monash University. No emission values have been assumed in the study for water and admixture use.

Constituent (material)	**CO_2-e/t**
Portland Cement	0.820
Fly ash (F -Type)	0.027
Slag (GGBFS)	0.143
Coarse aggregate	0.014
Fine aggregate	0.008
Water	0.000
Chemical Admixtures	0.000
Manufacture	0.015
Delivery	0.023

Table 3 – Constituent emission factors

It should be noted a number of limitations arise when comparing the manufacture of one cubic meter of concrete. Apart from the variation that arises with combinations of constituent materials and relative quantities, e.g. (1) binder/s, (2) water/cement ratios, (3) coarse and fine aggregate sources, type and quantity (4) chemical admixtures (5) manufacture (mixing) (6) transport distance of pre-mixed concrete.

Secondly the choices of member type and form of construction will be factors that govern, durability, fire resistance, maintenance and aesthetic requirements of the ultimate mix design and accordingly the above proportions.

These variables taken together can make one simple calculation difficult, moreover general statements about the CO_2-e emissions from one cubic meter of concrete somewhat meaningless and misleading.

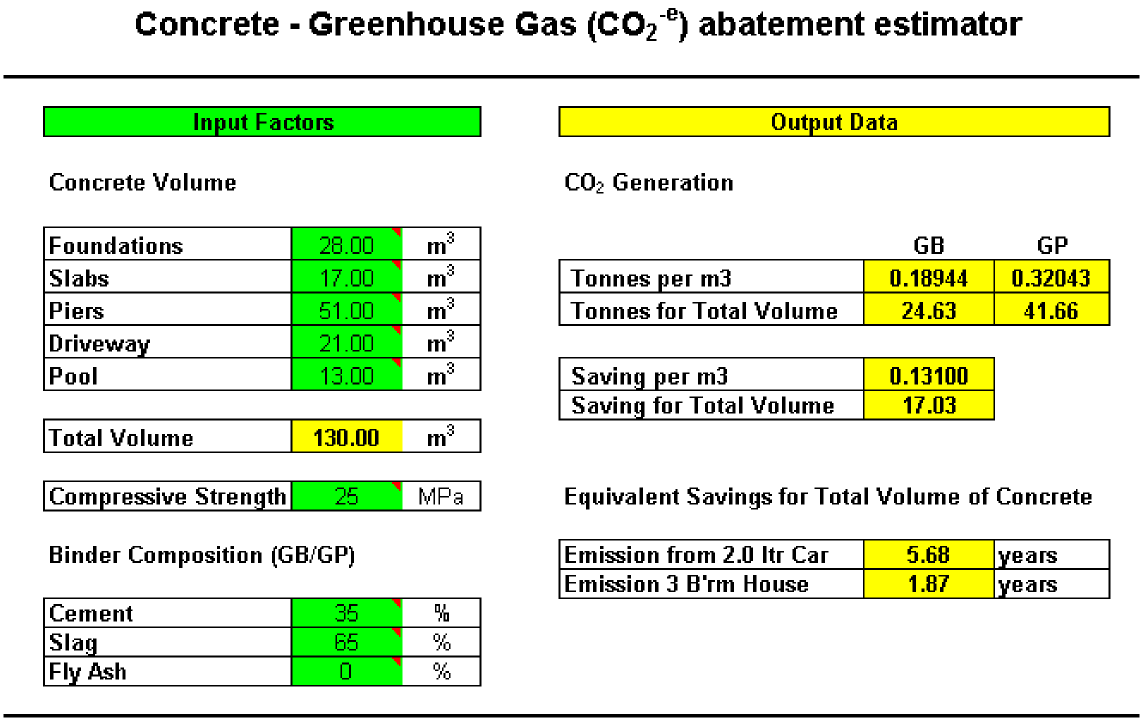
Using the resultant data and formulae, we can incorporate all variables [concrete mix design options] into a simplified CO_2-e estimator to assist architects, designers and consulting engineers to understand the CO2-e savings.

CASE STUDY A - INPUT FACTORS

For the construction of a domestic dwelling (four bedroom home) using approximately 130 cubic meters (m3) of 25 MPa concrete containing binder ratios of 35 percent Portland cement and 65 percent slag cement for the binder mix design.

Energy inputs for coarse and fine aggregates, water, concrete manufacture (mixing) and delivery to site have equally values. The independent variable are volumes of concrete required for each element of the structure, strength grade required, binders and combinations thereof [ratios].

The following Table 4 show the results using the criteria specified above.



Concrete - Greenhouse Gas (CO_2^{-e}) abatement estimator

Input Factors

Concrete Volume

Foundations	28.00	m^3
Slabs	17.00	m^3
Piers	51.00	m^3
Driveway	21.00	m^3
Pool	13.00	m^3

Total Volume	130.00	m^3

Compressive Strength	25	MPa

Binder Composition (GB/GP)

Cement	35	%
Slag	65	%
Fly Ash	0	%

Output Data

CO_2 Generation

	GB	GP
Tonnes per m3	0.18944	0.32043
Tonnes for Total Volume	24.63	41.66

Saving per m3	0.13100
Saving for Total Volume	17.03

Equivalent Savings for Total Volume of Concrete

Emission from 2.0 ltr Car	5.68	years
Emission 3 B'rm House	1.87	years

Table 4 - Total savings in CO_2-e emissions GGBFS 65 percent

The resultant total savings in CO_2-e emissions is 17.03 tonnes or 40 per cent reduction for these nominated input factors [mix design]. This is equivalent to emissions from a four-cylinder car for 5.68 years.

CONCLUSIONS

Projections from the Australian Greenhouse Office (AGO) based on the 2002 National Greenhouse Gas Inventory suggest that, without introducing any further abatement measures, Australian emissions will average 110 per cent over the Kyoto commitment period 2008 - 2012. So, the target is within sight, but clearly more needs to be done.

The paper argued that limited further reductions can be realised from the land use change sector for Australia to achieve 108 percent by 2008. An increased focus on selected sector mitigation strategies should be placed on the agenda. Limited options for ‘low hanging fruit’ reductions within Australia’s emission profile are evidenced by the land use changes reductions.

Sectors such as industrial processes could use recovered mineral resources in the form of coal combustion products (CCP’s) and various forms of iron blast furnace slag, which exhibits extremely low emission factors to displace or mitigate Australia's growing greenhouse gas emissions profile.

The results of this study show that the greenhouse gas emissions for the production one cubic meter of concrete can vary significant, due to independent variables of (1) binder/s, (2) water/cement ratios, (3) coarse and fine aggregate sources, type and quantity (4) chemical admixtures (5) manufacture (mixing) (6) transport distance of pre-mixed concrete. Also the choices of member type and form of construction will be factors that govern, durability, fire resistance, maintenance and aesthetic requirements of the ultimate mix design.

The CO2-e estimator has been demonstrated to minimise potential variation arising form input variables so that a more accurate saving of emissions resulting from the use of SCM's can be clearly understood.

The average weighted direct emission reduction for concrete containing 65 percent of GGBFS and 35 percent Portland cement is 40 per cent.

Clearly the increased use of SCM's is a matter for greater investigation within the construction sector for Australia. Given the 40 percent reduction demonstrated in this case study, with increased used of available SCM's, further greenhouse gas emissions cab be achieved.

The bonafides of SCM's are well developed in the literature for delivering improved durability performance of the built environment. The compelling argument that arises from the paper is that significant reductions in greenhouse gas emissions can be achieved without the need for significant additional capital resources and associated emissions from traditional cement manufacturing technologies.

REFERENCES

1. UNFCCC, Worldwide celebrations to mark Kyoto Protocol's entry into force on 16 February, Available: http://unfccc.int/files/press/releases/application/pdf/press050210events.pdf [Feb, 2005]
2. UNFCCC, A Summary of the Kyoto Protocol, Available: http://unfccc.int/essential_background/feeling_the_heat/items/2879.php [Jan, 2005]
3. Campbell, I., Australia leads the way in tackling greenhouse gas emissions, Available: http://www.deh.gov.au/minister/env/2005/mr16feb305.html [Feb, 2005]
4. McKibbin, W., *Sensible Climate Policy*. 2005, Lowy Institute for International Policy: Sydney, NSW, Australia. p. 26.
5. AGO, National Climate Change Adaptation Programme, Available: http://www.greenhouse.gov.au/impacts/index.html [Jan 2005]
6. AGO, AGO Funding Programmes, Available: http://www.greenhouse.gov.au/ago/funding/index.html [Jan 2005]
7. AGO, *National Greenhouse Gas Inventory 2002*. 2004, Australian Greenhouse Office: Canberra. p. 288.
8. UNFCCC, Greenhouse Gas Inventory Data - Total aggregate greenhouse gas emissions of individual Annex I parties 2002, Available: http://ghg.unfccc.int/index.html [Jan 2005]
9. UNFCCC, Greenhouse Gas Inventory Data - Selected Top Ten Annex I Countries by Emissions, Available: http://ghg.unfccc.int/index.html [Jan 2005]
10. UNFCCC, Greenhouse Gas Inventory Data - Anthropogenic CO2 emissions and removals from land-use change and forestry,a 1990-2002, Available: http://ghg.unfccc.int/index.html [Jan 2005]
11. Heidrich, C. *CCP Utilisation - a valuable resource*. in *Strategic Products for Government Infrastructure: Cementitious Materials for Concrete*. 2004. Sydney, NSW, Australia: NSW Department of Commerce, Sydney.
12. Heidrich, C. *Slag - the ultimate construction resource*. in *Strategic Products for Government Infrastructure: Cementitious Materials for Concrete*. 2004. Sydney, NSW, Australia: NSW Department of Commerce.
13. Collins, F. and J.S. Sanjayan. *The Challenge of the Cement Industry Towards the Reduction of Greenhouse Emissions*. in *Towards a Better Built Environment - Innovation, Sustainability, Information Technology*. 2002. Melbourne, Australia: International Association of Bridge and Structural Engineers.
14. Humphreys, K. and M. Mahasenan, *Toward a Sustainable Cement Industry - Substudy 8: Climate Change*. 2002, World Business Council for Sustainable Development: Switzerland. p. 61.
15. ABARE, *Cement extenters in Australia*. 1992, Australian Bureau of Industry Economics: Canberra. p. 45.
16. Ashby, J.B. *The J.C. Visek Memorial Address*. in *Concrete for the Nineties International Conference on the Use of Fly Ash, Slag, Silica Fume and Other Siliceous Materials in Concrete*. 1990. Leura, NSW, Australia.
17. Ryan, W.G. *The use fly ash and granulated blast furnace slag in concrete - an environmental impact assessment.* in *International Seminar on Technical and Environmental Advantages of Concrete Containing Fly Ash and Slag*. 1997. Sydney, NSW, Australia.
18. Hinczak, I., *Ground Granulated Iron Blast furnace Slag and Its Use in Concrete*. 1991, Concrete Insitute of Australia: Sydney, NSW, Australia. p. 4.

19. Munn, R.L. *Energy Resource Efficient Concrete*. in *Concrete 79*. 1979. Canberrra, ACT: Concrete Institute of Australia.
20. Potter, R.J., *Cement and Concrete and the Greenhouse Effect*. 1991, Cement Industry Federation: Canberra. p. 7.
21. ABS, *Manufacturing Production (Cement): 8301.0*. 2003, Australian Bureau of Statistics: Canberra. p. 12.
22. BHP Minerals Technology, *Case study: Cement production in Australia*, in *BHP Minerals Technology*. 2001, BHP Research Laboratory: Newcastle. p. 14.
23. CIF, *Cement Industry Environment Report*. 2003, Cement Industry Federation: Canberra, ACT. p. 24.
24. CIF, Clinker and Cement Production: 2002, Available: http://www.cement.org.au/industry.htm [Jan 2005]
25. CIF, Supplementary Cementitious Materials: 2002, Available: http://www.cement.org.au/industry.htm [Jan 2005]
26. CCUJ, *Country Report on Coal Research and Development in Japan*. 2000, Center for Coal Utilisation Japan: Japan. p. 20.
27. AGO, *AGO Factor and Methods Workbook*. 2004, Australian Greenhouse Office: Canberra, ACT. p. 46.