Use of Biomass as a Fossil Fuel Replacement in Australian Cement Kilns

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Abstract

Cement and cement products are essential materials in the Australian construction and building industry of today. The cement industry in Australia comprises Adelaide Brighton Ltd, Blue Circle Southern Cement Ltd and Cement Australia Pty Ltd. These three companies operate ten cement works, which together account for 100 per cent of integrated clinker and cement supplies in the country.

Environmental issues have taken on an increasing importance in the Australian Cement Industry, as evidenced by plant upgrades to improve energy efficiency and to reduce emissions, the release of a second Cement Industry Environment Report and a growing uptake of alternative raw materials and alternative fuels offering environmental benefits.

Alternative fuels that are being used by cement kilns to replace traditional fossil fuels include tyres, carbon anode dust & spent pot linings from the aluminium industry, a blend of recovered oils, dewatered sludges and grease trap emulsions and solvent based fuel. These alternative fuels currently account for approximately 6 per cent of thermal energy requirements for the Australian Cement Industry.

There are also a range of biomass-based alternative fuels that are able to be used by cement kilns including wood, tallow, dried biosolids, wheat residues, rice hulls, the woody component from composted organics, grape marc (residual skins from winemaking) and some types of process engineered fuel (for example, residual paper from material recovery facilities - MRFs).

The uptake of biomass-based alternative fuels is in its infancy, but is poised to increase in the coming year to similar tonnages as for existing alternative fuels. This would put biomass fuel use at 45,000 tonnes per annum (tpa) out of a total alternative fuel use of approximately 100,000 tpa. (However, biomass-based alternative fuels generally provide less thermal energy per tonne when combusted than the average for existing alternative fuels, meaning that the ‘energy delivered’ difference will be greater than the ‘tonnes delivered’.)

Advantages of using biomass as a replacement fuel include conservation of non-renewable fossil fuels, reduction in greenhouse gas emissions by offsetting fossil fuel use, recovery of a higher resource value from previously wasted materials, conservation of landfill space in some instances, a reduction in Nitrogen Oxide (NO_x), ability to utilise complementary alternative materials owing to reduction in ash content (coal replacement), less concerns regarding the composition of the fuel from a technical and community perspective (as compared against other alternative fuels) and an overall improved environmental performance. Additional benefits of a financial nature in terms of lower cost of fuel are also realised.

Barriers to the use of biomass include the capital cost for new processing and handling equipment (both on and off site), transport and logistics arising from the dispersed nature of the sources of the biomass fuel, process issues such as managing the quality of the fuel, wear on refractory brick linings, kiln ring build-up, lower productions rates and changed material recipe.

As the use of biomass-based alternative fuels is just beginning, there are still challenges to overcome in order to harness all of the advantages that biomass fuels have to offer the cement industry. These include gaining a ‘community licence to operate’, gaining regulatory approval and gaining access to potential supply that achieves the right balance of economic benefits for the fuel supplier and user.

Overall there is a growing interest within the cement industry regarding the use of alternative fuels (with specific attention given to biomass-based alternative fuels), as a means of achieving economic and environmental goals. Biomass in particular, has many advantages to offer the cement industry in Australia. The use of biomass is set to increase in the short term, provided that the technical barriers can be overcome in an economic manner and that fossil fuel replacement projects can gain the support of both the community and regulators.

(Note that this paper is based on a presentation given at the Bioenergy Australia 2003 Conference held 8-10 December in Sydney by Matthew Warnken. The paper was also co-authored by Damien Giurco).

Introduction and Background

Cement and cement products are essential materials in today's construction and building industry in Australia with an approximate production of six million tonnes of clinker annually.[1] The cement industry in Australia comprises Adelaide Brighton Ltd, Blue Circle Southern Cement Ltd and Cement Australia Pty Ltd. These companies operate ten cement works, which account for 100 per cent of integrated clinker and cement supplies in the country. The locations of the cement manufacturing facilities and their affiliations are shown in Figure 1.[2]

This paper considers the use of biomass as a fossil fuel replacement in Australian cement kilns. After describing the cement manufacturing process and its associated environmental concerns, the range of alternative fuels used in cement kilns is reviewed. Alternative fuels may be biomass or non-biomass and this paper aims to specifically determine the amounts of biomass fuels projected to be used in cement kilns around Australia in 2004 through a survey of cement manufacturers. The sentiments of cement kiln operators are also canvassed to gain a better insight into the technical and industry-wide barriers to the increased use of biomass as a fossil fuel replacement in the cement industry.

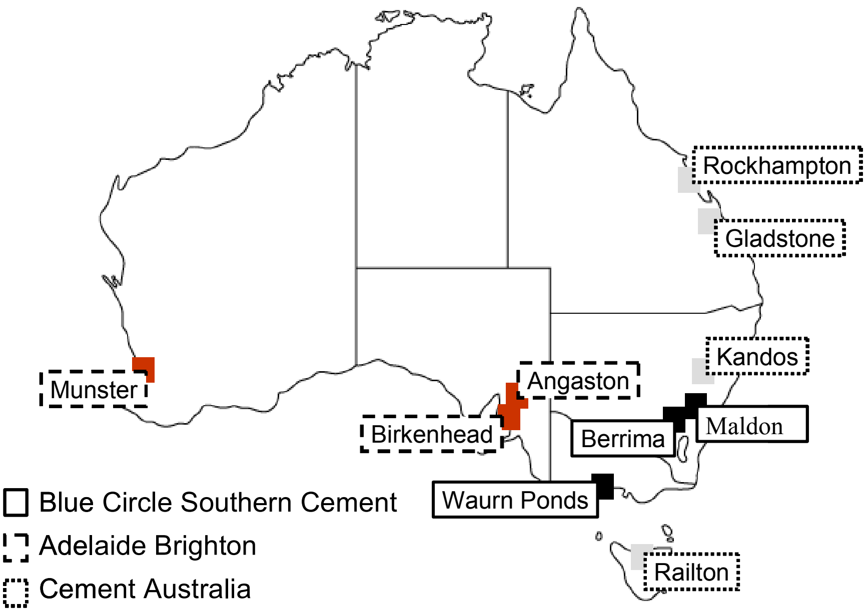

Figure 1 – Location of cement kilns around Australia
Source: Cement Industry Federation

As a snapshot of the status quo, Table 1 details the capacity and main fuel source currently used at each cement kiln around Australia compiled from information supplied by operating companies and the Cement Industry Federation. While several kilns use alternative fuels in small amounts, only Waurn Ponds and Gladstone have historically used alternative fuels as a feature of their fuel mix. However this is changing as many kilns are either commencing the use of, or are investigating the potential to, use alternative fuels.

Table 1 – Capacity of cement kilns around Australia and main fuel currently used

Plant	Annual Capacity (tonnes)	Main Fuel
Berrima, NSW	1,540,000	Coal
Maldon, NSW	300,000	Coal
Kandos, NSW	450,000	Coal
Waurn Ponds, VIC	500,000	Gas / Alternative

[1] Cement Industry Federation, 2003, 'Cement Industry Environment Report', Cement Industry Federation, Canberra, accessed at www.cement.org.au/environment/cement_industry_environment_report_2003.pdf, December 2003.
[2] Cement Industry Federation, 2003, 'Cement Industry Federation Website', accessed at www.cement.org.au, December 2003.

Plant	Annual Capacity (tonnes)	Main Fuel
Gladstone, QLD	1,600,000	Coal / Alternative
Rockhampton, QLD	140,000	Coal
Birkenhead, SA	1,300,000	Gas
Angaston, SA	250,000	Gas
Munster, WA	570,000	Gas / Coal

Basic Cement Manufacturing Process

The basic cement manufacturing process is shown in Figure 2. The main raw materials of limestone, clay and sand (and small amounts of iron oxide and alumina) are first mixed together and ground before being fed to the kiln. In a 'dry' kiln, exhaust gases are used to pre-heat the ground raw materials before entering the kiln, whereas in a wet kiln the raw materials are pumped into the kiln as a mixed slurry. The cement kiln itself is a long (50 to 200 m) rotary shaft (diameter 3.5 to 5.5 m) which gradually rotates.[3] Coal, gas or alternative fuels heat the rotating materials in the kiln to 1,450°C to produce clinker, an intermediate product which looks like dark grey pebbles. This is cooled and ground together with gypsum to produce either off-white or dark grey cement (the colour is dependant on the amount of iron oxide present – off white cement has virtually no iron oxide).

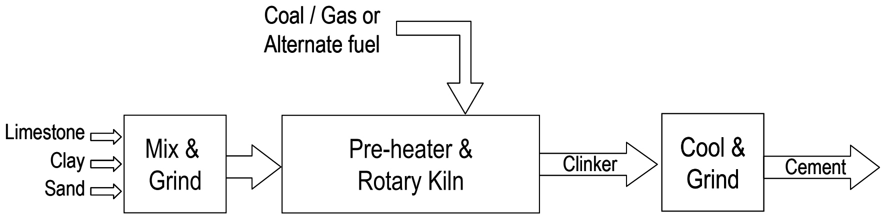

Figure 2 – Flowchart of basic cement manufacturing process

Operating and Environmental Factors in Cement Manufacture

Characteristic operating features of cement kilns include high flame temperatures in excess of 2,000°C and long fuel residence times within the flame zone of approximately 6 seconds. These conditions facilitate the use of an alternate fuel as the high temperatures and long residence time assist complete combustion. Furthermore, any ash content of the fuel is incorporated directly into the clinker product where it is bound up as part of the cement matrix.

Table 2 – Typical gaseous emissions from cement manufacture

Emission per tonne clinker	Typical Amount (kg)	Comment
CO_2 (Carbon dioxide)	750 to 800	Approximately half of this amount is from the combustion of fossil fuel (including that used to provide electricity to the plant) and the other half is from the calcination of limestone reaction which occurs in the kiln as the raw materials are converted into clinker.
NO_x (Nitrogen oxides)	1 to 4	Burning coal gives rise to most NOx while Natural Gas has lower amounts.
SO_x (Sulfur oxides)	0.5 to 1	Significant amounts of SOx are incorporated into the clinker product. However, coals with high sulfur content still give rise to the most SOx emissions.

A significant environmental effect arises from the provision of energy for clinker and raw material grinding, and kiln heating. The principal gaseous emissions resulting from cement manufacture are CO_2, SO_x and NO_x. The main solid waste from the process is in the form of particulates from grinding raw materials and clinker and dust from the kiln itself, although many kilns recycle the cement kiln dust directly back to the kiln.

[3] van Oss, H, and Padovani, A., 2002, 'Cement Manufacture and the Environment Part I: Chemistry and Technology', *Journal of Industrial Ecology*, 6(1): 89-105. Also see Mishulovic, A, 2003, 'Alternative materials', *International Cement Review* (January): 59-62.

The CO_2 values in Table 2 are taken from the Cement Industry Federation[4] and the NO_x and SO_x values are taken from van Oss and Padovani[5] and provide a guide to typical gaseous emissions, highlighting the contribution of fossil fuels.

Environmental issues have taken on an increasing importance in the Australian Cement Industry, as evidenced by plant upgrades to improve energy efficiency and to reduce emissions, the release of a second Cement Industry Environment Report and a growing uptake of alternative raw materials and alternative fuels offering environmental and cost benefits.

Alternative Fuels Used in Cement Manufacture

Alternative fuels used in place of conventional fossil fuels may be classed as 'non-biomass' or 'biomass' based. Those which the Australian industry has previously tried or is considering testing are listed in this section based on discussions with each of the companies operating cement kilns around Australia. An indicative 'as received' calorific value (CV) for each of the fuels is also given for comparative purposes against coal (26 mega-joules[6] per kilogram - MJ/kg) and natural gas (38 mega-joules per normal cubic metre – MJ/nm^3).

Non Biomass

Alternative fuels that are being used by cement kilns in Australia to replace traditional fossil fuels include end of life tyres (32 MJ/kg), carbon anode dust from the aluminium industry (22 MJ/kg), a blend of recovered fuel oils (38 MJ/kg), dewatered sludges and grease trap emulsions (the calorific value of these fuel types depends on the moisture content, with a low moisture content the CV can be up to 25 MJ/kg, however with a high moisture content the CV can be below 10 MJ/kg) and solvent based fuel (in some cases these fuels can be in excess of 40 MJ/kg depending on the type of solvent). These alternative fuels accounted for almost 6 per cent of thermal energy requirements (1.4 peta-joules[7] - PJ) for the Australian Cement Industry in the year 2002.[8]

Biomass

There are also a range of biomass-based alternative fuels that are able to be used by cement kilns, such as:

– wood - mainly derived from construction and demolition and commercial and industrial sources, as opposed to forest residue. Because of the low moisture content in the urban wood 'wastes' the calorific value is approximately 17 MJ/kg

– tallow - from the meat and livestock industry, with a calorific value of 38 MJ/kg

– dried biosolids - from sewerage treatment plants, with a variable calorific value of 9-13 MJ/kg depending on moisture and ash content

– wheat residues - the 'contaminated' grain (in that it is not fit for consumption) with a calorific value of approximately 15 MJ/kg

– rice hulls - residues from rice harvesting and processing, with a calorific value of 12-13 MJ/kg

– the woody component from composted garden organics (green waste) - with a calorific value of approximately 11 MJ/kg

– grape marc - the residual skins from winemaking after they have been processed to remove any remaining alcohol, colour and turmeric acid. Wet grape marc has a calorific value of approximately 10 MJ/kg, however if the marc is dried it can be as high as 16 MJ/kg

– some types of process engineered fuel - for example, residual paper from material recovery facilities. The calorific value of these fuels vary according the composition of the fuel, for example, a paper dominated fuel has a calorific value of approximately 20 MJ/kg

[4] Cement Industry Federation, 2003, 'Cement Industry Environment Report', Cement Industry Federation, Canberra, accessed at www.cement.org.au/environment/cement_industry_environment_report_2003.pdf, December 2003.
[5] van Oss, H, and Padovani, A., 2003, 'Cement Manufacture and the Environment Part I: Environmental Challenges and Opportunities', *Journal of Industrial Ecology,* 7(1): 93-126.
[6] 1 MJ = 10^6 joules
[7] 1 PJ = 10^{15} joules
[8] Cement Industry Federation, 2003, 'Cement Industry Environment Report', Cement Industry Federation, Canberra, accessed at www.cement.org.au/environment/cement_industry_environment_report_2003.pdf, December 2003.

- combination biomass and non-biomass fuels - for example, Teris (a company that is part of the Cement Australia Group) is looking to manufacture a fuel in Melbourne that is a combination of sludgy flammable wastes and sawdust. Called granular solid fuel it is anticipated to have a calorific value of 20 MJ/kg.

Use of Biomass Alternative Fuels in Australia

The uptake of biomass-based alternative fuels is in its infancy, but is poised to increase in the coming year (2004) to similar tonnages as for existing alternative fuels. This would put biomass fuel use at 45,000 tpa (41,000 tn wood and 4,000 tn tallow) out of a total alternative fuel use of nearly 100,000 tpa (20,000 tn tyres, 12,000 tn recovered oil, 12,000 tn solvents and 10,000 tn carbon dust). However biomass-based alternative fuels generally provide less thermal energy per tonne when combusted, than the average for non-biomass alternative fuels, meaning that their proportion of 'energy delivered' will be less than their proportion of 'tonnes delivered'.

If the anticipated levels of biomass usage are realised (in addition to increased usage of non-biomass alternative fuels), the cement industry will derive almost 11 per cent of its thermal energy requirements (2.6 PJ) from alternative sources (0.9 PJ from biomass and 1.7 PJ from non-biomass).

The sites using alternative and biomass fuels are detailed in Table 3, as well as the potential interest in further investigation of additional biomass fuels. From Table 3 it is noted that wood is set to be the most utilised biomass-based alternative fuel used in the Australian Cement Industry.

Table 3 – Current use of alternative fuels in Australian cement kilns and further interest in biomass based alternative

Plant	Non-biomass Use	Biomass Use	Potential Biomass
Berrima, NSW	Carbon anode dust, recovered oils, dewatered sludges, grease trap emulsions	n/a	Wood, garden organics, tallow
Maldon, NSW	n/a	Wood	Interested
Kandos, NSW	n/a	n/a	Interested
Waurn Ponds, VIC	Tyres, waste oil, carbon dust	Tallow	Dried biosolids, wood
Gladstone, QLD	Solvent based fuel, tyres	n/a	Interested
Rockhampton, QLD	n/a	n/a	n/a
Birkenhead, SA	Carbon anode dust	Wood	Residual wheat
Angaston, SA	n/a	n/a	Grape marc
Munster, WA	n/a	n/a	Interested
Railton, TAS	n/a	n/a	Wood derived granular solid fuel

Note that the above mentioned fuels only included those materials that were under investigation. The view of nearly all cement kilns contacted was that they would be happy to consider any biomass-based fuels where there were large amounts available at a low cost that would warrant spending the capital for the handling systems.

Drivers and Benefits of Biomass Fuels

The use of biomass fuel is being driven from both a cost and environmental perspective. Cement kilns are seeking to reduce the cost of fuel to their operations. Fuel costs for cement production are approximately between A$1.50 to A$3.00 per giga-joule[9] (GJ) with an energy requirement for cement production of approximately 4 GJ per tonne of clinker. Industry-wide in Australia, this gives an approximate total for the cost of fuel in excess of A$50 million per year. Consequently, significant savings are possible where biomass as a waste from other industries can be obtained at little or no cost (such as is possible where a waste generator wishes to avoid a landfill fee and will transport the biomass

[9] 1 GJ = 10^9 joules

directly to the cement kiln). An even better scenario for cement kilns are those biomass-based fuels that enter the kiln at negative cost, that is, the cement kiln is paid to receive them. This happens in instances where the cost of alternative management options is greater than the cost involved in preparing an alternative cement kiln fuel.

Environmental advantages of using biomass as a replacement fuel include conservation of non-renewable fossil fuels and a reduction in greenhouse gas emissions by offsetting fossil fuel use. Compared with fossil fuels, life cycle greenhouse gas emissions are reduced with the use of biomass, as the carbon in the biomass has recently been taken from CO_2 in the atmosphere into the plant as it grows and is simply released again back into the atmosphere upon burning in the kiln ('net neutral' carbon emissions).

The carbon released upon burning fossil fuels was taken from the atmosphere millions of years ago and when released now, contributes to greater concentrations of CO_2 in the atmosphere, thus giving rise to the greenhouse effect which induces climate change.

The use of biomass also allows recovery of a higher resource value from previously wasted materials which may have been disposed to landfill, burnt in the open with no energy recovery or left to slowly decompose in the open. Thus the use of biomass in some instances can contribute to saving landfill space, avoiding emissions associated with uncontrolled burning and avoiding any methane generation from slow anaerobic decomposition.

Additional benefits may include a reduction in Nitrogen Oxide (NO_x) emissions where the burning of biomass acts to reduce the kiln temperature, providing less favourable conditions for the formation of NO_x compounds. The actual emissions will also depend to a certain extent on the amount of nitrogen in the biomass. Also, by offsetting the amount of coal used with biomass, the ash content in the kiln is reduced. A lower ash content allows complementary raw materials to be used which can be obtained at lower cost than 'paying' for the ash in coal.

Technical and Financial Barriers to Biomass Utilisation

There are several technical and financial barriers which are slowing the uptake of biomass as an alternative fuel source. Technical process issues include:

- fuel quality management. Biomass based fuels are collected from a wide range of sources that are spread over large geographic regions. They are also sourced from suppliers that are not traditionally fuel preparers. This creates the potential for variable fuel quality, both in terms of calorific value and composition, which needs to be managed through specification and inspection
- wear and/or build up on refractory brick linings which can occur with some biomass fuels. The trial of grape marc as an alternative fuel was noted to contribute to kiln ring build-up, which diminished the efficiency of kiln operations
- changing 'recipe' of clinker manufacture. As was noted earlier, the fuel itself contributes part of the 'ingredient' requirements to make cement. The change in fuel configuration from fossil fuels to biomass based alternatives may require a change in the material recipe which can take time and may result in lower production rates during the implementation phase.

Furthermore, although the biomass may be obtained at little or no cost, there is still a set-up cost in re-equipping the plant to handle biomass. This includes the capital cost for new processing and handling equipment (both on and off site) as well as managing the transport and logistics arising from the dispersed nature of the sources of the biomass fuel. Capital costs for fuel delivery systems can be in the range of $A1-3 million dollars.

Another cost item that has been reported in association with the development of alternative fuel use has been the cost of trials and extra emission monitoring equipment which may not be required if conventional fossil fuels continue to be used. Several instances were also reported where State based regulators lowered the allowable emissions limits of operating licences in response to the uptake of alternative fuel use. This has increased the total project cost as a result of the capital cost of investing into upgrading plant and equipment to meet the new standards, in some cases making it cheaper to remain using fossil fuels.

Industry Challenges to Further Biomass-Based Fuel Use

As the use of biomass-based alternative fuels is just beginning, there are still challenges to overcome in order to harness all of the advantages that biomass fuels have to offer the cement industry. For example:

- gaining a 'community licence to operate'. There have been reported instances where a proactive community involvement program has been of benefit in the establishment of an appropriate alternative fuels program. Similarly, there are also cases where community groups have stopped the testing of any alternative fuels. This highlights the power of the community to influence projects and highlights the need for community support for these kind of projects
- gaining regulatory approval. As was previously noted, many kilns have had trouble negotiating with the regulator in order to gain permission to run trials and change the configuration of their operational conditions
- competition from electricity generators for 'RECable' fuels. Cement kilns do not generate electricity and as such they are ineligible to participate in the Mandatory Renewable Energy Target as established by the federal Renewable Energy (Electricity) Act 2000 and are unable to generate Renewable Energy Certificates (RECs). As a result, eligible power stations are able to pay more for supplies of biomass fuel, potentially to the disadvantage of the cement industry. This makes it difficult to gain access to a potential biomass-based fuel supply that achieves the right balance of economic benefits for the fuel supplier and cement kiln.

On a positive note, however, biomass based fuels can give rise to less concerns regarding the composition of the fuel from a technical and community perspective (as compared against other alternative fuels).

Future Outlook

Overall there is a growing interest within the cement industry regarding the use of alternative fuels (with specific attention given to biomass-based alternative fuels), as a means of achieving economic and environmental goals. Biomass in particular, has many advantages to offer the cement industry in Australia. The use of biomass is set to increase in the short term, provided that the technical barriers can be overcome in an economic manner and that fossil fuel replacement project can gain the support of both the community and regulators.

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For example: Warnken, M., and Giurco, D., 2003, 'Use of Biomass as a Fossil Fuel Replacement in Australian Cement Kilns', Warnken ISE, Sydney, accessed at www.warnkenise.com.au.