Characterisation of Mineral Wastes, Resources and Processing technologies – Integrated waste management for the production of construction material

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Industrial sector study on the utilisation of alternative materials in the manufacture of cement

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1. Scope

This report describes the results of an assessment of the role of alternative raw materials derived from mineral wastes in the manufacture of cement. The report reviews the manufacturing processes and markets for the material, sustainability issues in the sector, and the utilisation of alternative raw materials. These alternative raw materials may be added to the kiln to produce a ‘CEM I’ cement or as additions to produce blended cements (CEM II, CEM III etc.) It also describes the key properties that are required of these alternative raw materials, reviews current waste exchange mechanisms and recommends characterisation frameworks. It also mentions relevant standards and quality protocols to encourage wider utilisation of mineral wastes.

2. The Cement sector in the UK

Cement is one of the most commonly used products in construction. Cement manufacturers play an important role in the UK by satisfying market demand and supporting the country’s economy. Four main cement manufacturers operate in the UK; Tarmac Buxton Lime and Cement, Castle Cement, Cemex UK Cement and Lafarge Cement, who together own 15 plants across different locations in the country (Figure 1) (British Cement Association, 2007a).

Figure 1: Locations of cement plants across the UK (British Cement Association, 2007a)
The UK currently produces around 12 million tonnes of Portland cement each year and a further 1.5 million is imported. (British Cement Association, 2007a). The development of cement manufacture in the UK pertains to the availability of suitable raw materials and long-lasting reserves, such as good quality limestone and chalk, which can cover the demand of large cement plants (approximate production capacity 750,000 tonnes per annum per plant).

The cement making process requires significant amounts of energy. A direct fuel demand of ~ 3.7 GJ/t of clinker (European average) and a grinding power demand in excess of 100 kWh/t contributing the two major demands (Taylor et al 2006). CO₂ emissions from energy use depend on fuel type, but fossil fuel (coal/oil/gas) use dominates. Given the calcining reaction also emits some 500 kg CO₂/t of clinker, the sector is a major contributor to anthropogenic CO₂ emissions. The increasing cost of fuels, as well as the introduction of environmental legislation on climate change and sustainability initiatives has led the industry to consider the utilisation of alternative fuels and alternative mineral feedstock. This report focuses on the benefits and barriers of this utilisation and provides a characterisation framework for assessing potential materials.

2.1 Process overview

This report includes within its scope the cements that are covered by BS EN 197-1, 2000 (Cement-Part 1 Composition, specifications and conformity requirements for common cements). These cements (CEM cements) harden by a process that is primarily due to the hydration of calcium silicates. All contain Portland cement clinker. The Portland cement manufacturing process is broadly described by three main stages:

- Mining and mixing of raw materials - Limestone is quarried and prepared through a series of crushing and screening and subsequently mixed with clay and sand in a grinding mill to produce a fine powder (raw meal) suitable for a feed to a rotary kiln.

- Heating the meal: clinker production - Initially the feed is gradually heated in the pre-heater tower, before it enters the kiln. Once entering the kiln, the raw meal is exposed to very high temperatures (~1450 C), where it coagulates and forms the clinker. The kiln must maintain this high temperature continuously and to do so a variety of primary and alternative fuels are utilised.

- Grinding, blending and storing - When the clinker leaves the kiln, it passes through the clinker cooler and its temperature is reduced to approximately 100 °C. The clinker and gypsum are reduced in size by grinding in a ball mill to produce a homogeneous product.
Cement is stored in silos and transferred to various locations for use either in bulk through truck or rail transport or packed in bags.

A schematic diagram of the processes taking place in the manufacture of Portland cement-based cement is given in Figure 2. In addition to the manufacturing steps, Figure 2 also highlights the categories of alternative materials that may be added to the process, the stage that they may be added and the environmental impacts associated with the cement industry (i.e., emissions, cement kiln dust) and different types of cement end products.

Figure 2: Schematic diagram of the cement manufacturing process
2.2 Sustainability issues and the manufacture of cement

Through the World Business Council for Sustainable Development, the international cement sector has developed the Cement Sustainability Initiative in 1999, which set an action plan with specific objectives to be implemented by the industry. Cement manufacturers are concerned about sustainability, because the process (WBCSD, 2007):

- requires large quantities of raw materials (i.e. limestone) and fossil fuels to be consumed
- produces waste, CO2 and other emissions, which can cause adverse impacts to the environment and the climate
- may cause local impacts from quarry/cement dust, noise and traffic

The Cement Sustainability initiative puts objectives on eight major topics shown in Table 1.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource productivity</td>
<td>Improving eco-efficiency in quarrying, energy use and waste recovery and reuse</td>
</tr>
<tr>
<td>Climate protection</td>
<td>Monitoring, report and reduce CO2 emissions</td>
</tr>
<tr>
<td>Emission reduction</td>
<td>Reducing dust from quarrying, NOx, SOx and other airborne pollutants</td>
</tr>
<tr>
<td>Ecological stewardship</td>
<td>Improving land use and landscape management practices</td>
</tr>
<tr>
<td>Employee well-being</td>
<td>Health and safety</td>
</tr>
<tr>
<td>Community well-being</td>
<td>Working with local communities</td>
</tr>
<tr>
<td>Regional development</td>
<td>Participating in local affairs</td>
</tr>
<tr>
<td>Shareholder value</td>
<td>Creating more value for shareholder research</td>
</tr>
</tbody>
</table>

A guidance document published by the WBCSD for the selection and use of fuels and raw materials in the cement manufacturing process, states that cement companies can move towards eco-efficiency by (World Business Council for Sustainable Development, 2005):

1. Optimising existent processes: reducing fuel and material use and minimising pollution by optimising current manufacturing practices.
2. Waste co-processing: waste derived materials from other industries are utilised by the cement sector as fuels and raw materials
3. Eco-innovation: using new technology to produce and use cement products in a resource efficient way

The UK cement industry responded to WBCSD initiative by establishing the Sustainable Development Task Force (SDTF) in 2004. The sector has set sustainability road maps to follow and improve targets towards sustainability (British Cement Association, 2007b), which cover the eight key objectives of the Cement Sustainability Initiative (Table 1). The cement manufacturers have also been active on the utilisation of alternative materials as substitutes for virgin raw materials and fuels, as well as on the minimisation of waste produced by the manufacturing of cement. Waste produced by the cement making process mainly comprises cement kiln dust (CKD). The volumes of CKD have been reduced significantly by adjusting the cement making recipe and returning a significant quantity back into the production process (British Cement Association, 2007c). Cement plants also offer the benefit of using waste derived materials as a substitute for conventional fossil fuels, but also as an alternative resource of the primary raw mineral materials that form part of the cement. According to BCA, in 2005, 4.89% (by mass) of alternative materials and 14.28% (energy basis) of waste derived fuels were used, thus over a million tonnes of waste were diverted from landfill or incineration. This substitution rate is expected to increase in the future reaching a maximum of 60% utilisation in comparison to conventional fuels (British Cement Association, 2007c).

3. Alternative raw material use in the cement industry

Waste derived or by-product materials can be utilised from cement industries in multiple ways:

- to replace primary raw materials used in the cement clinker recipe
- to substitute conventional fuels such as coal, coke, and gas.
- to be utilised as additives in the production process of constituent cements to meet the requirements of BS EN 197-1: 2000. Cement. Composition, specifications and conformity criteria for common cements.

In the UK, additions are commonly made by the concrete producer at the mixer to produce blended or composite cement concretes. In order to clarify the types of substitution that could potentially take place, reference to a materials needs is provided in the following section. The
above alternative material categories have been adopted by this research project as the most appropriate classification scheme for by-products and waste materials that find use in cement.

3.1 Key requirements

Cement is made by treating at very high temperature a mixture of virgin materials, primarily limestone, marl or chalk, but also clay, sand and iron containing minerals. The oxides contained within those materials, CaO, Al₂O₃, SiO₂ and Fe₂O₃ respectively, under high temperature form the clinker, which later on in the process is ground with gypsum to form the final product. The chemical composition of the clinker is of great importance, as any changes can alter the reactivity, strength and setting time of cement.

A common meal recipe for the production of Portland cement consists of 75% (by mass) CaCO₃, 15% SiO₂, 5% Al₂O₃ and 5% Fe₂O₃. During the final stage of the process, an addition of 5% of gypsum is mixed and ground together with the clinker to form the final product.

In order to heat up the cement kiln and maintain the temperature at appropriate levels, a significant quantity of fuel (typically 3 GJ/t of clinker for the most modern dry-kiln plants to over 6 GJ/t of clinker for older wet-kiln designs) must be burnt, typically the source is coal, petroleum coke, gas or oil. Any ash content within the fuels combine with kiln feed materials and contribute to the structure of the clinker and form part of the final product. Overall energy use accounts for 30 to 40% of the production cost (World Business Council for Sustainable Development, 2005).

Different cement types to common Portland cement can also be created by mixing clinker with other constituents that comprise hydraulic or pozzolanic properties. These types of cements are called composite or blended cements and are discussed in detail later in this report.

3.2 Substitute materials and fuels

A series of interviews were held with the cement sector with the scope to monitor industry’s progress regarding the utilisation of waste derived materials in the past and present and also to speculate the future actions of this sector.
As mentioned earlier, alternative materials fall within three categories, materials utilised in cement’s main recipe, substitutes for fuels and by-products used in blended cements. These are listed in Table 2, Table 3, and Table 4 respectively.

### 3.2.1 Alternative materials in the clinker recipe

Numerous industrial and research scale trials have been undertaken to illustrate how alternative materials can substitute for virgin ones as sources of Si, Al, Fe and Ca. A summary of these trials is presented in Table 2.

Regarding characterisation, the approach followed by this project was to classify alternative materials according to the ingredients they contribute to the manufacturing process. As discussed earlier to produce cement, four major constituent oxides should be present and these are CaO, SiO\(_2\), Al\(_2\)O\(_3\) and Fe\(_2\)O\(_3\). The classes shown in the “ingredient” column of...
Table 2 correspond to these four essential constituents. Many waste derived materials comprise more than one type of oxide. For instance, incinerated sewage sludge ash consists mainly of SiO$_2$, but Al$_2$O$_3$ and Fe$_2$O$_3$ are also present and should be taken into account when composing the kiln meal.

This type of substitution (i.e. as input into the kiln as opposed to post-kiln blending with Portland Cement) has been implemented at a smaller scale than for alternative fuels. Nevertheless, it is anticipated that research will progress in the near future to allow greater substitution rates. The use of alternative materials in cement’s recipe is considered more difficult than for fuels because any alteration in cement’s chemistry will affect the quality of the end product. Also the composition and properties of the clinker, as well as the end product must follow certain technical specifications (i.e EN 197-1:2000).
Table 2: List of alternative materials that could potentially substitute virgin raw materials in the cement kiln meal (key: in the ingredient column: Si=SiO$_2$, Ca=CaO, Al=Al$_2$O$_3$ and Fe=Fe$_2$O$_3$)

<table>
<thead>
<tr>
<th>No</th>
<th>Recycled material</th>
<th>Progress</th>
<th>Ingredient</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>APC residues</td>
<td>Not in use</td>
<td>Si+Al+Fe</td>
<td>Trials undertaken in one site with bottom ash from a municipal waste incinerator</td>
</tr>
<tr>
<td>2</td>
<td>Bottom ash</td>
<td>Trials</td>
<td>Ca+Si+Al+Fe</td>
<td>Trials were undertaken in one site</td>
</tr>
<tr>
<td>3</td>
<td>Filter cakes</td>
<td>Trials</td>
<td>Si+Al+Fe</td>
<td>Pulverised fuel ash from power plants is used</td>
</tr>
<tr>
<td>4</td>
<td>Fly ash (PFA)</td>
<td>In use</td>
<td>Ca+Si+Al+Fe Si+Al+Fe</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Food filtering waste</td>
<td>Not in use</td>
<td>Si</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Foundry dust</td>
<td>Not in use</td>
<td>Fe</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Foundry sand</td>
<td>In use</td>
<td>Si</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Industrial sludge</td>
<td>Trials (literature source)</td>
<td>Ca+Si+Al+Fe</td>
<td>According to literature references, trials with industrial sludge have taken place in the past</td>
</tr>
<tr>
<td>9</td>
<td>Incinerated sewage sludge ash</td>
<td>Not in use</td>
<td>Si+Al+Fe</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>MSW incinerator plant ash</td>
<td>Not in use</td>
<td>Ca+Si+Al+Fe</td>
<td>Hazardous waste; may contain hazardous substances</td>
</tr>
<tr>
<td>11</td>
<td>Quarry fines</td>
<td>Trials/ in use</td>
<td>Si+Al+Fe</td>
<td>Trials were undertaken in one plant; they have been in use in an other plant</td>
</tr>
<tr>
<td>12</td>
<td>Roasted pyrite</td>
<td>Not in use</td>
<td>Fe</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Silica fumes</td>
<td>In use</td>
<td>Si</td>
<td>Commonly used in as an addition to concretes in relatively small quantities</td>
</tr>
<tr>
<td>14</td>
<td>Spent pot liners from aluminium manufacture</td>
<td>Not in use</td>
<td>Si+Al</td>
<td>May contain hazardous substances</td>
</tr>
<tr>
<td>15</td>
<td>Steel slag</td>
<td>Not in use</td>
<td>Ca+Si+Fe</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Waste gypsum</td>
<td>Not in use</td>
<td>Ca</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Water ochre colliery waste</td>
<td>Not in use</td>
<td>Fe</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Water treatment residues</td>
<td>Not in use</td>
<td>Ca+Si+Al+Fe</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>White dross nonmetallic residues</td>
<td>Not in use</td>
<td>Al</td>
<td></td>
</tr>
</tbody>
</table>

3.2.2 The use of alternative fuels

The rationale behind the increased use of waste derived fuels is found in industry’s objectives towards sustainability, in combination with the continuously increasing prices of conventional fuels. The key environmental impacts, relevant to alternative materials use, addressed in the sector’s sustainability agenda, look at ways to improve eco-efficiency including energy efficiency and waste recovery/reuse, climate protection through reduction of CO$_2$ emissions and minimisation of NOx, SOx, particulate matter and other airborne pollutants. The utilisation of alternative fuels could assist the industry to become more sustainable because:

- The use of waste derived fuels transforms cement kilns into waste co-processing facilities, while achieving a parallel conservation of fossil fuel resources. Both of these actions have
assisted the sector to progress towards the eco-efficiency objective. Also indirect energy savings are seen from reducing the extraction rate of fossil fuels.

- Alternative fuels, from a life cycle assessment perspective, have a lower carbon footprint than conventional fuels. The net CO$_2$ emissions resulting from the combustion of this type of materials in cement kilns are lower than other disposal routes such as incineration (CEMBUREAU, 1999b), furthermore the inorganic residues become integral part of the cement making product as opposed to a separate waste.

- The reduction of other emissions such as the NOx and SOx depends upon the alternative fuel in use and the emission control technology employed. Research so far has shown that for alternative fuels such as waste tyres, lower concentrations of NOx and SOx emissions have been recorded. Lower particulate matter emissions could be seen by substituting a conventional fuel in pulverized form with a waste derived fuel of coarse particle (lump) or liquid form. Indirect reduction of particulate matter emissions are achieved by less quarrying of fossil fuels. Dust generation associated with the combustion process (cement kiln dust CKD) has been mitigated by re-introducing the cement kiln dust in the kiln environment and thus reducing the amount produced.

The classification system for alternative fuels employed in this report follows the CEMBUREAU Best Available Techniques guidelines. Alternative fuels are subdivided in the following five categories (CEMBUREAU, 1999a):

1. Gaseous alternative fuels such as landfill gas, refinery waste gas and other.
2. Liquid alternative fuels, for instance spent solvents, paper sludge
3. Pulverised, granulated or fine crushed solid alternative fuels such as saw dust, dried sewage sludge
4. Coarse – crushed alternative fuels, like waste plastic, crushed tyres
5. Lump alternative fuels such as waste packaging, waste tyres.

Mixing and blending of waste derived fuels is essential prior to use in cement kilns and often some degree of processing is also required, in particular for liquid fuels such as spent solvents. A secondary industry has been developed to satisfy the processing and blending needs, which often comprise subsidiary companies of cement manufacturers.

The list of alternative fuels of Table 3 is not fully comprehensive but illustrates the breadth of interest in alternative fuel use by the UK cement sector. As noted alternative fuels can play a double role in the cement manufacturing process, providing the appropriate energy levels in the kiln and as a supplement to the composition of cement by contributing part of essential
ingredients such as silica from sewage sludge, calcium and aluminium from paper sludge, or iron from waste tyres.

Table 3: List of alternative materials that could potentially substitute conventional fuels in the cement making process (key: the ingredient column corresponds to class 1=gaseous fuel, class 2= liquid fuel, class 3= pulverized, granulated or fine crushed solid fuel, class 4= coarse crushed fuel, class 5= lump alternative fuel) (classes derived from Cembureau classification)

<table>
<thead>
<tr>
<th>No</th>
<th>Recycled material</th>
<th>Progress</th>
<th>Ingredient</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Colliery spoil</td>
<td>In use</td>
<td>Class 3</td>
<td>Often companies utilise own tips</td>
</tr>
<tr>
<td>21</td>
<td>Sewage sludge</td>
<td>In use</td>
<td>Class 3</td>
<td>High silica fuel</td>
</tr>
<tr>
<td>22</td>
<td>Animal derived fuel</td>
<td>In use</td>
<td>Class 3</td>
<td>Tallow, meat and bone meal</td>
</tr>
<tr>
<td>23</td>
<td>Paper sludge</td>
<td>In use</td>
<td>Class 2</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Waste paper</td>
<td>In use</td>
<td>Class 5</td>
<td>In use in one plant</td>
</tr>
<tr>
<td>25</td>
<td>Saw dust</td>
<td>Trials</td>
<td>Class 3</td>
<td>In impregnated form</td>
</tr>
<tr>
<td>26</td>
<td>Waste solvents</td>
<td>In use</td>
<td>Class 2</td>
<td>Secondary liquid fuels and recycled fuels</td>
</tr>
<tr>
<td>27</td>
<td>Waste plastics</td>
<td>In use/</td>
<td>Class 3, Class 4, Class 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>trials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Paint residues</td>
<td>In use/</td>
<td>Class 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>trials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Waste packaging</td>
<td>In use</td>
<td>Class 5</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Waste tyres</td>
<td>In use</td>
<td>Class 3, Class 4, Class 5</td>
<td>Useful addition of FeO</td>
</tr>
<tr>
<td>31</td>
<td>Waste oil/sluudge</td>
<td>Trials</td>
<td>Class 2</td>
<td>Trials were undertaken in one plant</td>
</tr>
<tr>
<td>32</td>
<td>Oil bearing soil</td>
<td>In use</td>
<td>Class 3</td>
<td>In one plant</td>
</tr>
<tr>
<td>33</td>
<td>Refused derived fuel</td>
<td>Trials</td>
<td>Class 3</td>
<td>May find application in the future</td>
</tr>
<tr>
<td>34</td>
<td>Landfill gas</td>
<td>Not in use</td>
<td>Class 1</td>
<td></td>
</tr>
</tbody>
</table>
Table 4: List of alternative materials that may be used for the production of blended cements

<table>
<thead>
<tr>
<th>No</th>
<th>Recycled material</th>
<th>Progress</th>
<th>Ingredient</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>Fly ash (PFA) (siliceous/calcareous)</td>
<td>In use</td>
<td>Pozzolan (siliceous); hydraulic and/or pozzolan (calcareous)</td>
<td>Common by-products for blended cements</td>
</tr>
<tr>
<td>36</td>
<td>Silica fume</td>
<td>In use</td>
<td>Pozzolan</td>
<td>Well established by-product</td>
</tr>
<tr>
<td>37</td>
<td>Ground granulated blast furnace slag - GGBS</td>
<td>In use</td>
<td>Hydraulic</td>
<td>Commonly used in blended cements</td>
</tr>
<tr>
<td>38</td>
<td>Limestone</td>
<td>In use</td>
<td>Reactive ingredient</td>
<td>Commonly used</td>
</tr>
<tr>
<td>39</td>
<td>Metakaolin</td>
<td>Some use</td>
<td>Pozzolan</td>
<td>Sometimes used in as an addition to concrete products in relatively small quantities</td>
</tr>
<tr>
<td>40</td>
<td>(FGD) gypsum</td>
<td>Not in use</td>
<td>Calcium sulphate source</td>
<td>Future use - depending on availability</td>
</tr>
</tbody>
</table>

3.2.3 The use of alternative materials in blended cements

In Table 4 alternative materials that may be used in the production of blended and composite cements are presented. The production of blended cements has been investigated by past research and various relevant bibliographic references can be viewed in the Waste-Product Pairings (WPP) database. BS EN 197-1:2000 sets specification on the use of alternative materials. Blended cements that meet the requirements of BS EN 197-1 are produced by co-grinding or blending Portland cement clinker with by-products such as fly ash, ground granulated blast furnace slag or other materials. Alternative materials used in the production of blended cements commonly exhibit desirable reactive properties, for instance behaving as a pozzolan (active silica source) or latently hydraulic material. Cement manufacturers are beginning to supply blended (CEM II) cements routinely (Price, 2007).

Alternative materials used in the production of blended cements are treated by the industry as by-products, although legislation still classifies them as waste. The cement sector overcomes this barrier, by operating under an integrated pollution prevention and control permit. When acquiring such license, the cement sector works together with the Environment Agency to make sure that all appropriate measures for permitting the use of a variety of alternative materials including waste derived fuels and materials used in kiln meal are in place. In the UK, it is also common practice for concrete manufacturers to produce blended cement concretes at the concrete mixer using alternative materials such as GGBS and pfa, rather than blended cements prepared in advance by the cement producers.
3.2.4 Benefits and barriers associated with the use of alternative materials

Table 5, Table 6, and Table 7 present industry’s current response regarding the utilisation of alternative materials plus the potential benefits/barriers, as well as the framework of analysis required during the exchange process. The content of these tables should be read in conjunction with Figure 3, Figure 4 and Figure 5 respectively, which list in detail the benefits, barriers and testing requirements.

In Table 5 the results of potential use of alternative materials in the kiln meal are shown. Benefits and barriers have been classified into six different groups, namely, material related, economic, environmental, legal, organisational and social. A description of the employed classification system has been given in the report on database development (Petavratzi and Barton, 2006).

Potential benefits on the use of alternative materials in cement clinker manufacture fall within the material related, economical, environmental, organisational and social classes. Material related benefits are seen from the reduced use of virgin materials, from reduced processing, (for instance foundry sand does not require the energy consuming stage of grinding), from large availability of alternative material resources that can provide continuous supply and from desirable composition elements. Environmental benefits are seen from diverting waste from landfill, reducing CO$_2$ emissions and reducing energy consumption associated with further processing. Finally the use of alternative materials assists the sector to improve its environmental profile and to move towards the production of greener products.

The majority of barriers seen from the use of alternative materials in the kiln meal are “material related”. Parameters such as the low availability of adequate quantities of resources, the compositional variability, or adverse minor elements in the composition of waste derived materials (i.e. heavy metals), as well as the geographical proximity for a desirable source, may discourage or prohibit their use. For example, the proportion of steel slag that can be used in clinker manufacture is limited by its minor element content. Environmental constraints are commonly associated with the composition of a specific material, whereas economic barriers are seen from additional handling and processing. For instance, the utilisation of water treatment residues requires certain alterations (i.e. drying) to take place, to allow the material to be fed to the process, which could raise the cost of manufacturing. Legislative barriers are seen from the composition of waste, in particular with materials that have been classified as hazardous. A ranking system has been employed to define the significance of the reported constraints ranging from 1, being significant, to 4, meaning that future work is required to determine its importance.

Another important barrier that the sector has to face regarding the utilisation of waste-derived materials in kiln’s meal is to provide the essential continuity to the process. This is not an easy task as cement manufacture is a large consumer of primary materials and market
demand is high. Finally, all cement industries own quarries therefore virgin material sources are readily available to them at low cost and with guaranteed continuity of supply. The use of alternative materials needs to provide clear benefits to the sector, such as desirable properties, or a profit (i.e. through charging a gate fee) to be an attractive option.

Initiatives such as the Aggregates Levy, sustainability agendas and relevant legislation on the conservation of natural resources are expected to work as drivers for the utilisation of alternative materials in cement kiln recipe. By substituting part of virgin raw materials with waste-derived ones, the industry will improve further its eco-efficiency image, particularly the substitution of part of limestone with some other Ca-rich materials (i.e. pulverised fuel ash, paper ash) could lower CO$_2$ emissions derived directly from it. A further advantage may be to help companies to meet their environmental policy and corporate social responsibility obligations to shareholders.

The Green Guide for Specification and BREEAM, both of which provide an assessment of environmental impact of buildings or components, include within their assessments a significant element associated with global warming. They also take into account (positively) the use of recycled materials instead of primary materials. The use of alternative fuels and raw materials in cement impacts positively in this regard.

The column on analysis (Table 5) describes the analysis requirements in determining the suitability of a waste derived material as an ingredient in cement clinker. Testing takes place for alternative materials, the kiln feed and the end product. The table refers only to these three broad categories and not to specific tests, which are shown in detail in Figure 3. Testing on alternative materials takes place either by waste producers who seek an output for their material, or the cement industry. The composition of kiln’s feed is examined during the blending/ pre-heating stage and at the end of the clinker manufacturing process. The end product cement needs to meet certain technical specifications (for properties such as heat of hydration and setting time), as required by BS EN 197-1:2000, thus cement should be tested further.

To date only a few alternative materials find use in kiln’s feed, but it is anticipated that higher utilisation will be seen in the near future, in order the sector to achieve the 60% material substitution target set in their sustainability strategy.
Table 5: Classification of industry’s response regarding the utilisation of alternative materials in cement’s recipe. (Key: recycled material No corresponds to list show in

<table>
<thead>
<tr>
<th>Recycled material No</th>
<th>Potential Benefits</th>
<th>Potential Barriers</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1MR+EC; 2EC; 3ENV; 4EC</td>
<td>1MR=2; 2MR=2</td>
<td>1(excluding particle size); 2(exc. CaO); 3</td>
</tr>
<tr>
<td>2</td>
<td>1MR+EC; 2EC; 3ENV; 4EC</td>
<td>10MR=2</td>
<td>1; 2; 3(exc. surface area)</td>
</tr>
<tr>
<td>3</td>
<td>1MR+EC; 2EC; 3ENV; 4EC; 5ORG</td>
<td>2MR=2; 3MR+ENV+LE=3</td>
<td>1; 2(exc. CaO); 3 (exc. surface area)</td>
</tr>
<tr>
<td>4</td>
<td>1MR+EC; 2EC; 3ENV; 4EC; 5ORG; 6ENV; 7MR</td>
<td>9MR=3; 2MR=3; 7MR=1</td>
<td>1(exc. moisture content); 2; 3(exc. colour)</td>
</tr>
<tr>
<td>5</td>
<td>3ENV; 4EC; 5ORG</td>
<td>1MR=2</td>
<td>1; 2(exc. CaO, Al₂O₃; Fe₂O₃); 3(exc. colour and surface area)</td>
</tr>
<tr>
<td>6</td>
<td>1MR+EC; 2EC</td>
<td>1MR=2; 3MR=3</td>
<td>1(exc. particle size); 2(CaO, SiO₂, Al₂O₃); 3(exc. colour and surface area)</td>
</tr>
<tr>
<td>7</td>
<td>2EC; 3ENV; 7MR; 8MR+EC+ENV</td>
<td>8MR-EC-ENV=3; 6MR=3; 7MR=1</td>
<td>1(exc. mineralogy+ moisture content); 2(CaO, Al₂O₃; Fe₂O₃ (exc. colour and surface area))</td>
</tr>
<tr>
<td>8</td>
<td>1MR+EC; 2EC</td>
<td>1MR=2</td>
<td>1(exc. mineralogy+ moisture content+LOI); 2; 3(exc. density, colour and surface area)</td>
</tr>
<tr>
<td>9</td>
<td>1MR+EC; 2EC; 3ENV; 4EC; 5ORG</td>
<td>1MR=2</td>
<td>1(exc. moisture content); 2 (exc. CaO); 3(exc. colour and surface area)</td>
</tr>
<tr>
<td>10</td>
<td>1MR+EC; 2EC; 3ENV; 4EC; 5ORG</td>
<td>4LE=1(fly ash); 5MR-EC=2; 2MR-ENV-LE=3</td>
<td>1(exc. moisture content);2; 3(exc. colour and surface area)</td>
</tr>
<tr>
<td>11</td>
<td>1MR+EC; 2EC; 3ENV; 4EC; 5ORG</td>
<td>3MR-ENV-LE=3</td>
<td>1(exc. moisture content);2(exc. SiO₂, Al₂O₃; Fe₂O₃); 3(exc. colour and surface area)</td>
</tr>
<tr>
<td>12</td>
<td>1MR+EC; 3ENV</td>
<td>2MR=2</td>
<td>1(exc. moisture content); 2(exc. CaO); 3(exc. colour and surface area)</td>
</tr>
<tr>
<td>13</td>
<td>1MR+EC; 2EC</td>
<td>1MR=2</td>
<td>1(exc. moisture content);2(exc. CaO, SiO₂; Al₂O₃ (exc. colour and surface area)</td>
</tr>
<tr>
<td>14</td>
<td>1MR+EC</td>
<td>1MR=2</td>
<td>1(exc. mineralogy + moisture content); 2(exc. SiO₂); 3</td>
</tr>
<tr>
<td>15</td>
<td>9MR; 2EC</td>
<td>1MR=2</td>
<td>1(exc. mineralogy+ moisture content); 2(exc. CaO, Fe₂O₃); 3(exc. density, colour and surface area)</td>
</tr>
<tr>
<td>16</td>
<td>10MR; 11MR+EC</td>
<td>3MR-ENV-LE=2; 9MR=3; 1MR=2</td>
<td>1(exc. moisture content); 2(exc.Al₂O₃); 3(exc. colour and surface area)</td>
</tr>
<tr>
<td>17</td>
<td>1MR+EC; 2EC; 3ENV; 4EC; 6ENV</td>
<td>1MR=1; 9MR=3</td>
<td>1(exc. mineralogy); 2(exc. SiO₂, Al₂O₃; Fe₂O₃); 3(exc. colour)</td>
</tr>
<tr>
<td>18</td>
<td>1MR+EC; 2EC;</td>
<td>1MR=2</td>
<td>1; 2(exc. CaO, SiO₂, Al₂O₃); 3(exc. surface area)</td>
</tr>
<tr>
<td>19</td>
<td>1MR+EC; 2EC; 3ENV; 4EC; 5ORG</td>
<td>7MR=2; 11MR-EC-ORG=3; 3MR-ENV-LE=3; 1MR=2</td>
<td>1; 2; 3(exc. surface area)</td>
</tr>
</tbody>
</table>
Table 2: Numbers shown in benefits/barriers/analytical techniques link to Figure 3; Categories of benefits/barriers: MR=material related, EC=economic, ENV=environmental, LE=legal, SO=social, ORG=organisational; ranking system shown in barriers: 1=significant, 2=important, 3=less important, 4=future work will define significance
### 1. Testing on alternative materials

- Particle size
- Mineralogy
- Chemistry
- Other constituents
- Total sulphur
- Chloride content
- Heavy metals
- Loss on ignition
- Moisture content

### 2. Testing on kiln feed

- CaO
- SiO$_2$
- Al$_2$O$_3$
- Fe$_2$O$_3$
- MgO

### 3. Testing on end product

#### Physical properties
- Cement chemistry
- Chlorine content (Cl % by mass)
- Sulphate content (SO$_3$ by mass%)
- Alkali content (NaO$_2$ equiv)
- Water soluble hexavalent chromium
- Phosphate content
- Particle size- fineness
- Apparent and bulk density
- Surface area
- Insoluble residues (% by mass)
- Loss on ignition (% by mass)
- Colour

#### Engineering properties
- Compressive strength (MPa)
- Initial setting time (min)
- Soundness (mm)
- Durability

### Potential Benefits

1. Reduced use of virgin materials
2. Charge a gate fee
3. Less waste sent to landfill
4. Reduction in waste disposal costs
5. Improve company’s environmental profile
6. Reduce emissions
7. Large availability
8. Grinding of primary sources can be avoided
9. Contribution of fluorine/ calcium fluorsilicate flux
10. Composition
11. Fluxing agent

### Potential Barriers

1. Low availability
2. Compositional variability
3. Composition
4. Hazardous waste
5. Further processing
6. Quantity requirements
7. Geographical proximity
8. Particle size-reactivity
9. Not common practice to be used pre-kiln
10. Heavy metals content
11. Handling problems

Figure 3: Potential benefits, barriers and analysis requirements on the utilisation of alternative materials/waste in cement’s recipe
Table 6 presents industry’s response on the utilisation of alternative fuels in cement making. Benefits seen from the use of alternative fuels are mainly environmental, but economical, material related, organisational and social may also be found. The conservation of fossil fuel resources, the reduction of CO$_2$ emissions, the waste co-processing opportunities, the recycling of combustion residues and the diversion of waste from landfill are the major environmental advantages of this type of substitution.

The use of alternative fuels is economically beneficial for the cement sector, particularly when a profit can be made by charging a gate fee to waste suppliers. Commonly, the gate fee is a cheaper option than other disposal routes (i.e landfill, incineration) for waste producers. There is also an overall economical and environmental benefit associated with cement kilns and the use of alternative fuels, that of avoiding the development of new incineration facilities. Cement kilns nowadays operate under the Waste Incineration Directive (WID) and the environment in the kiln is considered a safer option than traditional incinerators, as the kilns commonly operate at higher temperatures and longer residence times (ensuring high destruction efficiencies for organic pollutants).

Barriers associated with the use of waste derived fuels fall within the material related and environmental classes. Some legal, organisational and social barriers have also been recorded. Low availability, adverse composition, low calorific content, compositional variability, problematic consumption and build up/ chemical attack in the kiln are some of the material related barriers that are often seen. For instance, the calorific content of animal derived fuel is low or the combustion of saw dust is often problematic. In order to avoid some of these barriers, the cement industry performs blending of fuels prior to use. Environmental barriers are seen from adverse emissions associated with some waste materials or from the build up inside the kiln, which can cause excessive production of cement kiln dust. Social constraints are seen from alternative fuels that raise public health concerns. Hazardous waste or the composition of certain materials may cause legislative constraints, whereas additional requirements on handling, storage, processing and sorting are considered as organisational constraints. The utilisation of alternative fuels is well established and it is expected to be extended further in the near future, as the benefits seen so far are strong and significant.
Table 6: Classification of industry’s response regarding the utilisation of alternative fuels in cement making. (Key: recycled material No corresponds to list show in Table 3; Numbers shown in benefits/barriers/analytical techniques link to Figure 4; Categories of benefits/barriers: MR=material related, EC=economic, ENV=environmental, SO= social, ORG= organisational; ranking system shown in barriers: 1= significant, 2= important, 3= less important, 4= future work will define significance)

<table>
<thead>
<tr>
<th>Recycled material No</th>
<th>Potential Benefits</th>
<th>Potential Barriers</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>1MR=3</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>21</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>2SOC=2; 3MR=3</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>22</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>4MR=2; 3MR =3; 5MR-ORG =3</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>23</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>7MR-ORG=2; 6MR-LE-ENV=2; 5MR-ENV=3</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>24</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>1MR=1</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>25</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>8MR=2; 3MR=3; 7MR-ORG=3; 9LE-ENV=3</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>26</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>8LE=3; 5MR-ENV=3</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>27</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV, 12LE-ENV</td>
<td>4MR-LE=2; 6ENV=2; 5MR-ORG=3</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>28</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>10LE-ENV=3; 5ENV=3; 6ENV=3</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>29</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>5MR-ENV=3; 4MR=2</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
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<tr>
<td>30</td>
<td>1ENV, 5EC, 6MR-ENV, 6EC, 9ENV, 11MR, 13ENV-SOC-ORG</td>
<td>11EC=2; 12LE-ENV-SOC=2</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
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<tr>
<td>31</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>1</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>32</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
<td>13MR=2; 7EC-ORG=2</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>33</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV, 5EC, 6MR-ENV</td>
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<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>34</td>
<td>1ENV, 2ENV, 3ENV, 4EC-ENV</td>
<td>1</td>
<td>1, 2, 3, 4, 5, 6, 7, 8</td>
</tr>
</tbody>
</table>
Testing on substitute fuels
1. calorific content
2. moisture content
3. content of halogens
4. sulphur content
5. heavy metal content
6. suspended soils content
7. ash content
8. physical characteristics (i.e. boiling point, flash point, size range etc)

Potential Benefits
1. reservation of fossil fuels resources
2. reduction in CO₂ emissions
3. waste treatment without energy consumption
4. waste management solution at no extra cost
5. gate fee charge
6. recycle of combustion residues
7. calorific content - energy
8. cheaper fuel
9. Lower NOx and SOx emissions
10. Recycling of ash residues
11. Source of iron
12. less waste is sent to landfill
13. health and safety

Potential Barriers
1. low availability
2. public perception
3. low calorific content
4. composition
5. build up and chemical attack
6. emissions
7. handling - storage
8. combustion
9. health and safety
10. hazardous waste
11. collection, sorting, processing
12. public health concerns
13. variability

Figure 4: Potential benefits, barriers and analysis requirements on the utilisation of alternative fuels in cement manufacture
As stated previously, the production of blended / composite cements is covered by technical specifications and standards. In addition alternative materials in use are considered as by-products by the sector. Commonly materials with pozzolanic and/or hydraulic properties such as pulverised ash and ground granulated blastfurnace slag (ggbbs) find an application∗.

Table 7: Classification of industry’s response regarding the utilisation of alternative materials in blended cements. (Key: recycled material No corresponds to list show in Table 4 Table 4; Numbers shown in benefits/barriers/ analytical techniques link to Figure 5; Categories of benefits/ barriers MR=material related, EC=economic, ENV=environmental, SO= social, ORG= organisational; ranking system shown in barriers 1= significant, 2= important, 3= less important, 4= future work will define significance)

<table>
<thead>
<tr>
<th>Recycled material No</th>
<th>Potential Benefits</th>
<th>Potential Barriers</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>1MR; 4MR (calcareous); 2ENV; 3MR</td>
<td>6MR-EC-ENV=3, 9MR =3, 4MR =1</td>
<td>2, 3, 4, 5, 6, 12, 13 + 7 (for calcareous)</td>
</tr>
<tr>
<td>36</td>
<td>1MR; 2ENV</td>
<td>10 SOC-ORG=2; 8EC=2; 3MR-ORG=2</td>
<td>2, 3, 10, 12, 13</td>
</tr>
<tr>
<td>37</td>
<td>4MR; 2ENV; 3MR-EC</td>
<td>6MR-EC-ENV=3, 4MR =2, 7MR =3; 8EC=2</td>
<td>1, 2, 3, 13 (exc. Pozzolanicity)</td>
</tr>
<tr>
<td>38</td>
<td>9MR; 6MR; 2ENV</td>
<td>5MR=3</td>
<td>2, 3, 8, 9, 11, 13 (exc. Pozzolanicity)</td>
</tr>
<tr>
<td>39</td>
<td>1MR; 2ENV</td>
<td>3EC-ORG=3; 4MR-EC=2</td>
<td>2, 3, 10, 13</td>
</tr>
<tr>
<td>40</td>
<td>7ENV-EC-LE; 8MR-EC-ORG</td>
<td>1MR-LE=2; 2EC=2</td>
<td>2, 3, 13</td>
</tr>
</tbody>
</table>

Blended cements utilise less Portland cement and for that reason they are considered as a “greener” alternative than CEM I (Portland cement). Finding a local source of such alternative materials and further processing requirements such as grinding (energy intensive) are commonly seen as barriers to their use. For materials like silica fume, a highly active pozzolana, economic factors (e.g. high purchase cost) may also discourage the sector to use them, except for special applications. The use of blended cements is expected to increase in the future as both industry and government are concerned about “greener” approaches to production. It is also worth noting that some of the alternative materials or blends of alternatives can be used as a complete substitute for Portland Cement. For example recent research demonstrated specification quality dense concrete block production using wastepaper sludge ash (WSA) combined with ground granulated blastfurnace slag (GGBS) (Bai J 2007). The success of this and other projects is recognised by inclusion of WSA and GGBS in the waste protocols project∗ which aims to set out the criteria for such wastes to be considered fully recovered prior to reuse.

∗ A quality protocol is currently being produced for pulverised fuel ash and others are anticipated. These protocols are intended to define compositional and quality requirements and sources that meet their requirements they are expected to be regarded as “by-products” rather than “waste” (Environment Agency, 2007).
Testing on alternative materials used in blended cement

1. (CaO+MgO)/ SiO$_2$ ratio
2. chemistry
3. other constituents
4. reactive CaO (%)
5. Free CaO (%)
6. Free lime (%)
7. Reactive SiO$_2$
8. CaCO$_3$ (%)
9. methylene blue adsorption
10. specific surface (BET) m$^2$/g
11. total organic carbon
12. LOI (%)
13. Testing on cement (moisture content, particle size, density, particle size-fineness, sulfate content, chloride content, alkali content, phosphate content, MgO (%), compressive strength, initial setting time, heat of hydration, colour, soundness, insoluble residue, Pozzolanicity, water soluble chromium, durability)

Potential Benefits

1. pozzolanic material (like pfa)
2. environmental benefits
3. positive influence on concrete workability
4. latently hydraulic (like ggbs)
5. concrete durability
6. early strength reduction
7. low CO$_2$ emissions
8. reduced cost composite cement

Potential Barriers

1. not suitable for use with steel reinforcement
2. small percentage of total cement market
3. handling
4. geographical proximity
5. high purity is required
6. grinding is required
7. slower strength development
8. purchase cost
9. compositional variability
10. health and safety

Figure 5: Potential benefits, barriers and analysis requirements on the utilisation of alternative materials in blended cement
3.3 Characterisation Framework

The following figures (Figure 6, Figure 7, and Figure 8) present the proposed characterisation framework on the use of alternative materials in cement manufacture. Alternative materials are classified according to the primary ingredients they contribute to the making process. The proposed characterisation framework is expected to initiate / facilitate material exchanges and to find application as a guidance tool both for waste producers and waste users. Waste producers could benefit by identifying whether the cement sector could be a possible output for their waste. On the other hand, waste users could implement a similar type of categorisation to existent material exchanges and gain additional knowledge and ideas on “new” waste derived materials and their fit into the cement making process.
Figure 6: Characterisation framework on the utilisation of alternative raw materials in cement’s recipe.
Figure 7: Characterisation framework on the use of alternative fuels in cement industries

Figure 8: Characterisation framework on the use of alternative materials for the production of blended cements
4 Guidance on Assessing alternative raw materials in cement

4.1 Waste Exchange and the cement industry

The cement sector could easily follow the anchor-tenant model and develop symbiotic relationships with various local or regional companies that provide materials for cement making. According to this model, the cement manufacture represents the anchor industry, namely the core of various synergies that are built around it. Making cement requires raw materials and fuels and as discussed in previous sections a large variety of industries could supply materials to this sector (i.e. chemical industries, power plants, water treatment plants and other). All these different industries can provide valuable resources from secondary materials and thus avoid disposal to landfill and incineration plants.

Currently material exchanges taking place are based on simple waste exchanges, but the sector is looking to transform such exchanges to symbiotic linkages. The benefits seen from industrial symbiosis are continuity of supply, long-term security, mutual dependency and therefore mutual growth and development.

4.2. Future Developments

The cement industry has been active in the utilisation of materials mainly through the use of alternative fuels, but progress has also been seen on substituting virgin raw materials. The sector expects to increase the substitution of materials up to 60% in the future therefore greater utilisation rates of alternative materials will be achieved. Blended/composite cements present a variety of environmental benefits and it is anticipated that their production will also move forward.

Lately the production of new type alternative cementing systems, based on calcium sulphates is increasing. These include calcium(sulfo)aluminate and calcium sulfate based cements, which can make use of various by-products such as gas desulphurisation gypsum, calcium silicate and calcium aluminate hydrates. The main benefit seen from the production of these types of cements is lower CO₂ emissions.

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1 More information about the anchor-tenant model can be found in the Ceramic Products case study report (Petavratzi and Barton 2006)
5 Overview Roadmap for utilising alternative raw materials in the cement industry

In the appendix, shown at the end of this report, a roadmap regarding the utilisation of alternative materials from the cement sector has been constructed. The purpose of that roadmap is to summarise the experience gained through this research project and to provide a route that could help the industry to achieve higher substitution of virgin materials and more synergetic linkages to evolve.

6 References

CEMBUREAU (1999a) "Best Available Techniques" for the cement industry. Brussels, CEMBUREAU.
PRICE B, (2007) "CEM II Cements in the UK: the way forward?", Concrete, Vol 41, Number2, pp 36-38
WORLD BUSINESS COUNCIL FOR SUSTAINABLE DEVELOPMENT (2005) Guidelines for the selection and use of fuels and raw materials in the cement manufacturing process. WBCSD.
Appendix: Roadmap for the Cement Industry

Cement Industry’s Objective = Sustainability

1. Resource productivity: eco-efficiency, natural resources conservation, energy efficiency, waste reuse/ recovery
2. Climate protection: monitoring & reduction of CO₂
3. Emissions reduction: monitoring & reduction of NOx, SOx, particulate matter, etc
4. Demand satisfaction: logistics, continuity in supply

Why sustainability promotes the utilisation of alternative materials

The use of waste-derived materials transform the cement industry into a waste co-processing facility; less virgin material input and fuel is required; blended cements = more energy efficient option→ all above assist the industry to work towards the resource productivity objective.

Alternative fuels have a lower carbon footprint and their use has proved a more friendly environmental approach (lower CO₂) than incineration. The substitution of limestone may reduce CO₂ emissions produced in the kiln.

The substitution of virgin materials and fuels with alternatives may result to lower emissions, especially from quarrying and mining activities.

Higher utilisation rates of alternative materials can be achieved through compliance with logistics and provision of continuous supply, which can assist the industry to satisfy demand.
Road map on the utilisation of alternative materials from the cement sector
Potential benefits

- Material related: substitution of raw materials, desirable properties
- Economical: profit through a charge of a gate fee; reduced cost of fuels
- Environmental: reduced emissions; conservation of natural resources, recycle combustion residues (for alternative fuels), waste management; less OPC (for blended/ composite cements)
- Organisational: improve industry’s environmental profile; green products
- Legal: reduced emissions; good practice may push certain wastes to become by-products; natural resources conservation; sustainability; waste management (through co-incineration)
- Social: cleaner environment; waste management; less quarrying and mining
Potential barriers

- Material related: logistics; continuity in supply, geographical proximity, variability; undesirable properties; adverse impacts to end products
- Economical: additional costs on handling, storage, processing requirements and monitoring/ control installations; licensing; transport
- Environmental: increased emissions; health and safety implications; increased levels of cement kiln dust
- Organisational: additional installations; corporate responsibility
- Legal: licensing; hazardous waste; CO₂ and other emissions; waste transfer and storage
- Social: public perception upon the utilisation of waste; health and safety implications
Future work

- *Quality protocols*: preparation of quality protocols for the utilisation of alternative raw materials (similar to protocol for substitute kiln fuels)

- *Life cycle assessment*: introduce life cycle assessment as a decision making tool on waste exchange