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

WRT 177 / WR0115

Industry Sector Study:

Heavy Ceramic (Brick)

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Industrial sector study on the utilisation of alternative materials in the manufacture of mineral wool insulation

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Contents

1 Scope

The scope of this case study is to identify ways to use alternative materials as a resource in the manufacturing process of ceramic products, such as bricks. Initially a short literature review covering the brick manufacture and specific sustainability objectives is given to illustrate what actions the sector has taken until today and what changes are envisaged in the near future. Following that, the current status in the use of waste and alternative materials from ceramic manufacturers is discussed and data collected from interviews with the industry are presented. The benefits seen and barriers faced in waste-product pairings are examined in detail and analysis testing required in initiating and establishing a synergy is also recorded. Collected data assisted to the development of a characterisation framework, which sets the *fit-for-purpose criteria* on the use of alternative materials in the brick making process.

2 The brick manufacturing sector in the UK

2.1 Process Overview

The brick manufacture is considered a historic industry and the making process is well established and covered by technical specifications and standards. Bricks are produced from clay extracted from various areas around the UK. The term *brick* clay is often used by the industry to describle the type of clay and shale used in the manufacture of products such as facing and engineering bricks, ceramic tiles, clay pipes, roofing tiles and other ceramic products (BGS, 2007). From all the above ceramic products, bricks comprise the most dominant one in the UK. Due to the different characteristics and properties of the clay used (i.e soft plastic clays, mudstones) the aesthetics and sometimes the physical/ mechanical properties of bricks vary significantly on a regional level.

Commonly brickworks operate in close proximity to clay quarries, owned by the same company, so as to satisfy their needs for raw materials. The volume of extracted clay is low in comparison to other materials from the mineral industries (i.e aggregates) and in order for extraction to be viable, the ratio of clay to overburden (waste rock) should be quite high. A schematic representation of brick clay resources in Great Britain is presented in Figure 1.

The market of bricks presented significant changes with the introduction of concrete blocks as the latter replaced common bricks in construction. This resulted to a shift of the market in producing facing bricks, used for aesthetic purposes (Figure 2). The use of 'facing bricks' accounts for over 90% of demand (BGS, 2007) (DTI construction statistics) The production of facing bricks appears quite stable for the last seven years. Common and engineering bricks are still produced, but in much lower quantities (Figure 2), whereas the manufacturing of facing bricks have expanded significantly and currently is described by several products with different colours, textures, surfaces and sizes. Clay tiles have also been affected by the introduction of concrete. Ceramic pipemaking has declined considerably due to competition from concrete and plastic pipes. The only products that show an increase in demand are roofing tiles, which have become more popular recently (BGS, 2007).

Bricks are produced either by extrusion or by the 'soft-mud' process. Extrusion is the commonest option. Two schematic diagrams describing the manufacturing processes are presented in Figure 3 and Figure 4. Bricks are dried prior to firing. For firing of bricks a linear kiln (tunnel kiln) is used, which commonly operates on natural gas.

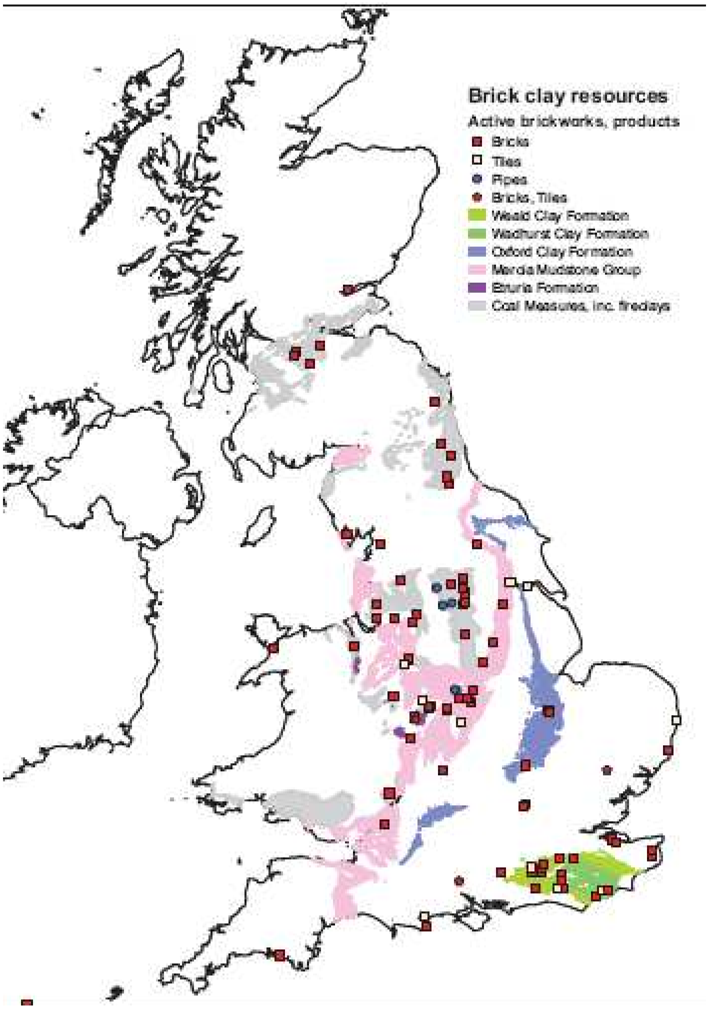

Figure 1: Brick clay resources in Great Britain (BGS, 2007)

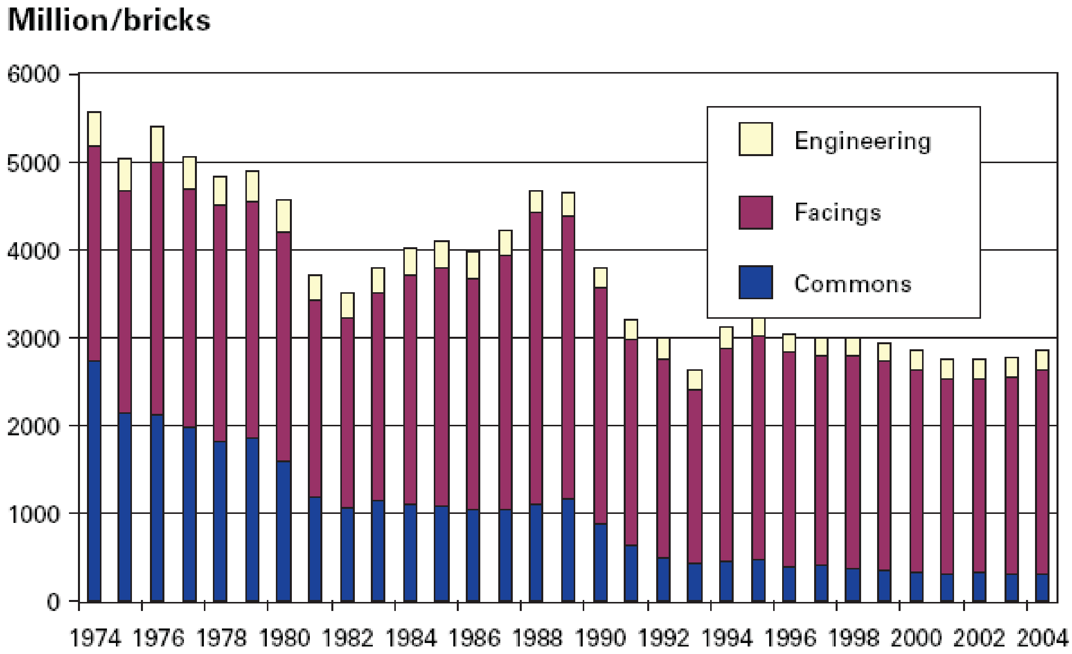

Figure 2: Production of bricks in Great Britain (by type, between 1974-2005) (BGS, 2007)

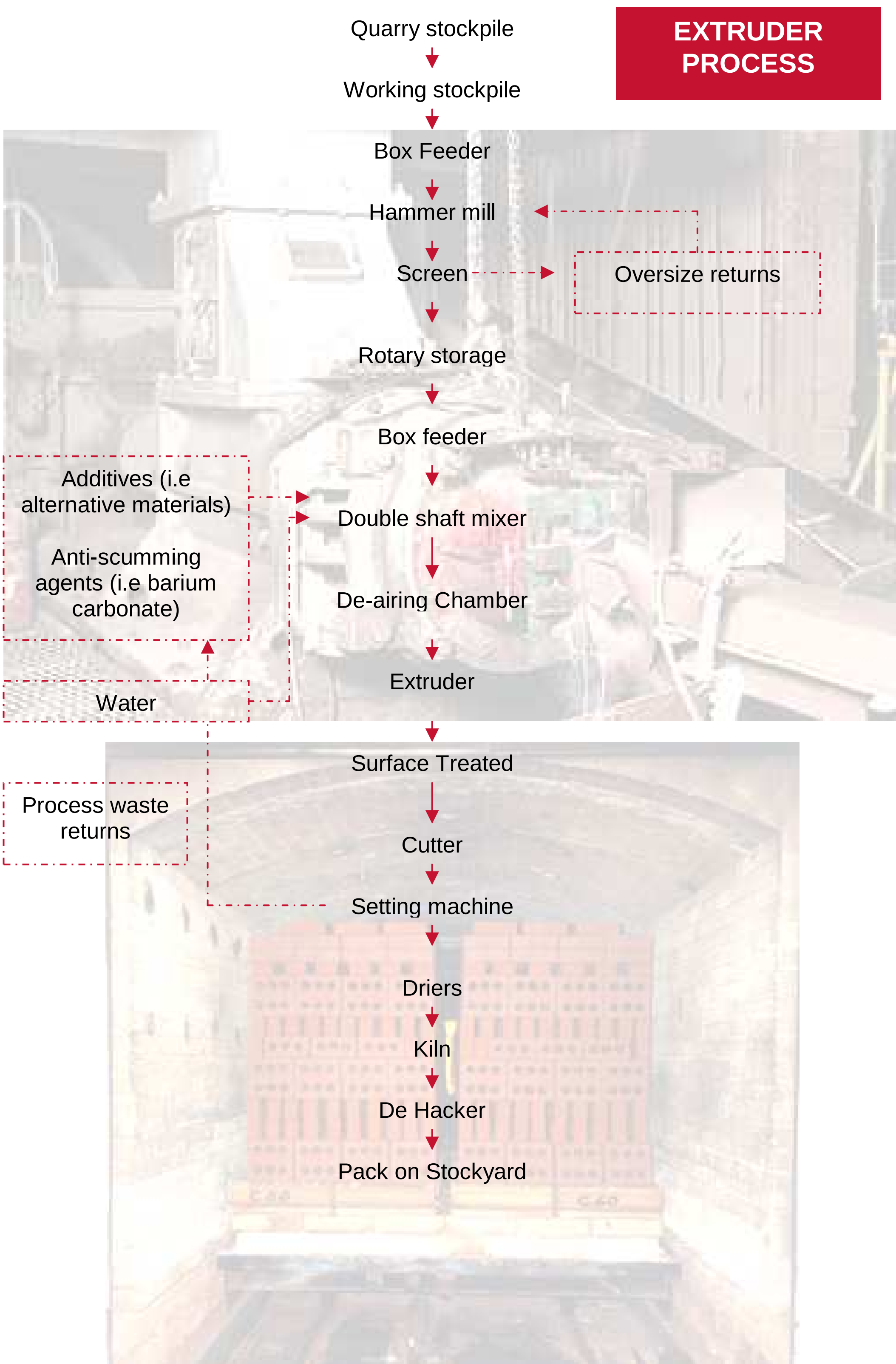

Figure 3: Brick manufacturing – the extrusion process

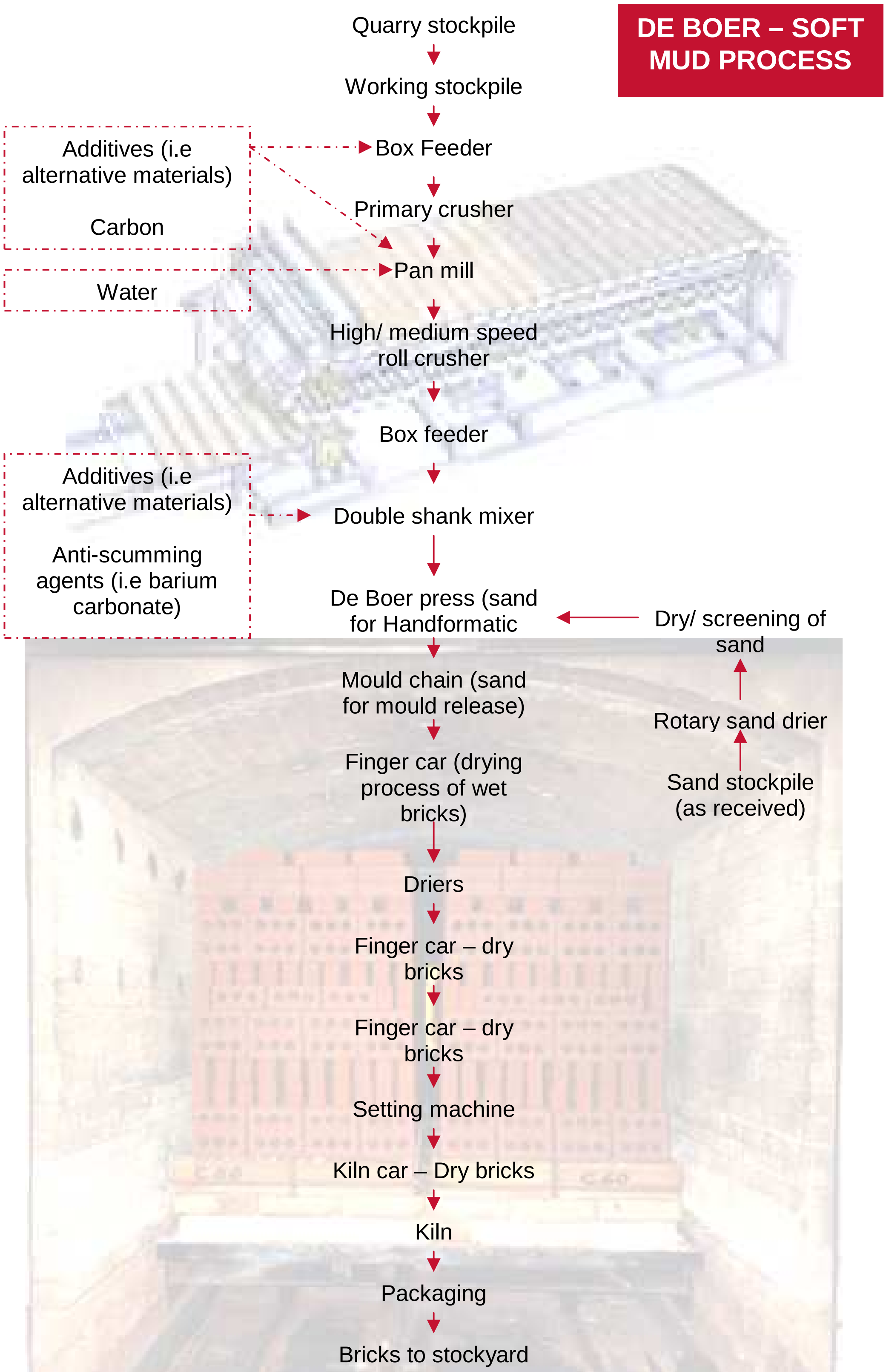

Figure 4: Brick manufacturing – the “soft-mud” process

2.2 Sustainability issues and brick manufacture

The environmental impacts of the brick industry sector are associated with energy efficiency and consumption, atmospheric emissions and resource efficiency (sustainable production and consumption). Energy efficiency in kilns will have to be optimised to meet the energy reduction targets (over 10% by 2010) and the atmospheric emissions of carbon gases, hydrogen fluoride should also be reduced. Regarding resource efficiency the brick manufacture (Brick Development Association, 1999):

- complies with standards set by planning permissions
- aims to source raw materials locally and to keep stock on site or within close proximity
- acquires clay from other quarries that produce it as a by-product
- recycles clay waste
- considers the use of alternative materials that will substitute for the clay body
- considers the life cycle thinking as a way to improve sustainability and
- will work close with bodies such as the Building Research Establishment in order to produce “green specifications”

Brick manufacturing is a well established industry and there is a potential to introduce alternative materials in the process, so as to satisfy the demand for large portfolios of products with different aesthetic properties. The manufacture of products with recycled content must represent an objective for companies serving the construction sector. Customer demand and expectations have changed significantly and there is a place for a market of “green products”.

3 Alternative Raw Materials usage in the brick industry

3.1 Key Requirements

From discussion with the industry it was found out that different alternative materials may play a different role in the brick making process. Therefore alternative materials may work as:

- Clay substitutes: these materials will substitute the clay body
- Fillers: Often primary sand is used as filler in bricks, however several other materials could be used for this purpose.
- Body fuels: Clays are often rich in organic matter, however if organic content is low in the primary materials then alternative materials could be utilised to contribute the necessary fuel elements.
- Colourants: In traditional brick making the colour of the bricks derives from the clay body. The facing bricks market though is very competent and requires a variety of end products with different aesthetic properties. Certain alternative materials could be used as colourants.
- Fluxing agents: Fluxing agents enable the lowering of the firing temperature of bricks and they can result to direct energy savings.

3.2 Substitute Materials

Data from the brick sector were collected after discussions with Ibstock bricks, Hanson Building products and Akristos is presented in Table 1 and Table 2. Table 2 has fewer entries than Table 1 in terms of the number of recycled materials as the work undertaken meant that benefits and barriers for dredged harbour sediments and fine steel sludge could not be established.

Table 1: List of waste/ alternative materials with the potential to be used in bricks and the progress made so far by the industry in UK.

No	Recycled material	Progress	Comment
1	Clay off cuts	In use	Recycled internally
2	Grog	In use	Recycled internally
3	Scrubber waste	In use in one plant	Waste from own scrubber
4	Pulverised fly ash	In use	Traditional alternative material for brick making
5	Town ash	In use	Traditional alternative material for brick making
6	Coke breeze	In use	Traditional alternative material for brick making
7	Coal fines	In use	Traditional alternative material for brick making
8	Slag	In use in one plant	Blast furnace slag from the steel manufacture
9	Sugar starch	In use in a couple of plants	
10	Saw dust	In use in one plant	
11	Quarry fines	In use	
12	ISSA	In use in one plant	
13	WTR	In use in one plant	
14	Pottery glaze	In use	
15	Foundry Sand	In use/ trials	A small amount of primary sand is recycled internally. Trials were undertaken for the use of foundry sand in bricks
16	Bone ash	Lab/ work trials	
17	Bottom ash	Lab trials	
18	Container glass	Lab/ work trials	R&D work was undertaken via WRAP funded projects
19	CRT glass	Lab trials	Some work was undertaken via WRAP funded projects
20	Dredged harbour sediment	Lab trials	
21	Fine steel sludge	Lab and work trials	
22	Ti oxide rich waste	Lab trials	
23	Plastic residues	Lab trials	
24	Pottery clay	Lab trials	
25	Paper sludge	Lab trials	
26	Paper ash	Lab trials	

Table 2: Classification of industry's responses regarding the utilisation of alternative materials/ waste in bricks. (Key: Recycled material No= look at list of Table 1; Numbers shown in benefits/ barriers/ analytical techniques columns= lists of Figure 5; Categories of benefits/ barriers: MR=material related, EC=economic, ENV=environmental, ORG=organisational, SO=social; Barriers are also classified according to their significance (similar to WPP database)➔ 1=significant, 2=important, 3=less important, 4=future work will define significance)

Recycled material No	Potential benefits	Potential barriers	Analytical techniques
1	8 (MR), 9(EC)		
2	8 (MR), 9(EC)	4 (MR=1), 2 (MR=2)	
3	5 (MR), 9 (EC)	6 (LE=1, ENV=3), 2 (MR=3, ORG=3), 8(MR=2)	
4	1 (MR), 3 (MR), 5 (MR), 7 (ENV), 8 (MR), 12 (MR)	3 (MR=1), 19 (MR=3), 11 (MR=3), 9 (EC=2), 5 (ORG=4), 20 (ENV=3)	
5	1 (MR), 4 (MR)	9 (EC=4), 3 (MR=1), 5 (ORG=4)	
6	1(MR), 4 (MR), 13(SO), 14 (ORG)	11 (MR=2), 3 (MR=2)	8, 12
7	1 (MR), 4 (MR), 13 (SO), 14 (ORG)	11 (MR=2), 3 (MR=2), 20 (ENV=2)	8,12
8	5 (MR), 7 (MR), 8 (MR), 13 (SO), 14 (ORG)	8 (MR=1), 10 (EC=2), 15 (LE=2)	1,2,3,4,5,6,7,8 ,9,10,11
9	6 (MR), 15 (MR), 13 (SO), 14 (ORG)	4 (MR=1), 1 (ORG=3), 5 (ORG=3)	1,2,3,4,5,6,7,8 ,9,10,11
10	1 (MR), 5 (MR), 7 (ENV), 13 (SO), 14 (ORG)	20 (ENV=3), 1 (ORG=3)	8
11	3 (MR), 4 (MR), 5 (MR), 6 (MR), 7 (ENV), 8 (MR), 13 (SO), 14 (ORG)	1 (ORG=3)	1,2,3,4,5,6,7,8 ,9,10,11
12	2 (MR), 5 (MR), 4 (MR), 7 (ENV), 13 (SO), 14 (ORG)	8 (MR=1), 7 (LE=4), 17 (SO=3), 5 (ORG=4), 2 (EC=4), 9 (EC=4), 16 (ORG=2), 4 (LE=2)	1,2,3,4,5,6,7,8 ,9,10,11
13	4 (MR), 6 (MR), 8 (MR), 13 (SO), 14 (ORG)	1 (ORG=4), 5 (ORG=4), 13, (EC=4), 9 (EC=4), 16 (ORG=2), 15 (LE=2)	1,2,3,4,5,6,7,8 ,9,10,11
14	3 (MR), 4 (MR), 5 (MR), 7 (MR), 8 (MR)		1,2,3,4,5,6,7,8 ,9,10,11
15	5 (MR)	14 (MR=2), 20 (ENV +EC = 2)	2,3,8,11,13, 14
16	2 (MR), 5 (MR), 8 (MR)	8 (MR=2), 7 (LE=4), 16 (ORG=2), 1(ORG=3)	1,2,3,4,5,6,7,8 ,9,10,11
17	1 (MR), 4 (MR)	4 (EC=4), 3 (1=MR), 5 (ORG=4), 11 (MR=2)	12
18	2 (MR), 11 (MR)	10 (EC=1), 13 (EC=2), 2 (ORG=4), 19 (MR=2), 5 (ORG=4), 18 (MR,LE, SO=3), 8 (MR=2), 16 (ORG=2), 20 (ENV=3)	2,5,7,9
19	2 (MR)	20 (ENV=3)	1,2,3,4,5,6,7,8 ,9,11,13
22	4 (MR), 8 (MR)	10 (EC=1), 16 (ORG=2), 1 (ORG=2)	1,2,3,4,5,6,7,8 ,9,10,11
24	3 (MR), 4 (MR), 5 (MR), 7 (ENV), 8 (MR)	4 (MR=1), 9 (EC=2)	
25	1 (MR)	1 (ORG=4), 5 (ORG=4), 18 (MR, LE=4), 13 (EC=4), 9 (EC=4), 16 (ORG=2), 11 (MR=2), 3 (MR=2)	2,4,5,6,7,8,9, 11
26	5 (MR)	18 (MR, LE=4), 5(ORG=4), 9 (EC=4), 3 (MR=2)	1,2,7,8,9,11

List of Analytical techniques:

List No	Analytical technique
1	Mineralogy
2	Chemical analysis
3	Colour measurements
4	Green strength
5	Durability
6	Compression strength
7	Bulk density
8	Particle size analysis
9	Water absorption
11	Efflorescence
12	Calorific content
13	Shrinkage
14	Appearance after firing
15	Decision upon the type of clay body
16	Firing temperature
17	Other

List of potential benefits:

List No	Potential benefit
1	Fuel content
2	Flux
3	Green strength
4	Colourant
5	Filler
6	Plasticity
7	Reduce emissions
8	Clay substitute
9	Reduce cost (i.e waste disposal)
10	Large volume/ availability
11	Improve end product's strength
12	durability
13	Products with recycled content
14	Improve company's environmental profile
15	Anti-scumming agent
16	other

List of potential barriers

List No	Potential barriers
1	Handling problems (specify)
2	Processing is required (specify)
3	Compositional variability
4	Low volumes/ availability
5	Storage requirements
6	Hazardous waste
7	Require a waste management licence
8	End product properties (specify)
9	Transport cost
10	Purchase cost
11	Calorific content
12	Energy consumption
13	Processing cost
14	Composition (specify)
15	Low landfill cost
16	Absence of testing facilities
17	Public perception
18	Health and safety issues (specify)
19	Particle size
20	Increased emissions (i.e dust, CO_2)
21	Other

Figure 5: Lists of analytical techniques, potential benefits and barriers concerning the brick industry

Alternative raw materials are considered for use by brick manufacture as a potential cost effective solution to access materials with desirable compounds/ properties. Such materials are normally priced cheaper than raw materials and for certain streams (i.e sewage sludge, bone ash) some profit could be made by charging producers a gate fee.

The majority of the materials presented in Table 1 correspond to mineral waste, although some other non-mineral streams have also been identified such as sugar starch and the saw dust. Most of the benefits seen from their use are material related (Table 1). That is to say they contribute in one way or another (i.e. comprise a fuel body or a colourant) to the properties of the end product. This conclusion clearly demonstrates industry's need for materials that might provide different aesthetic results to facing bricks.

Several alternative materials have been tested or considered for use by the brick manufacture. Nevertheless, only well established materials find application in the majority of brickworks, the so called "traditional alternative materials" (Pulverised fuel ash, coke breeze, coal fines and town ash). Even with such materials though, problems may arise. For instance the compositional variability of fly ash or the calorific content of coal fines, town ash can become significant barriers to companies if they do not satisfy the specifications set during experimentation. In order to overcome such barriers companies tend to limit their supply links to specific sources (i.e a particular power station) even if supply from elsewhere becomes apparent at lower cost. Medium to long term contracts are signed between the producer and the user to legalise the exchange process. The length of the contract is affected by the logistics of sullply and demand as well as by economic (i.e. purchase cost, transport cost), business and market related factors (i.e. competition) and technical issues (i.e. maintenance requirements). Also the use of traditional alternative materials is very much dependant upon the availability of close proximity sources. Once a proximal producer of traditional alternative by-product exists then their use is taken under consideration. Commonly traditional alternative materials are added to the brick body at percentages between 5 to 10%. Most of the brickworks operate under the Pollution Prevention and Control (PPC) regime, therefore waste management licences are not required for the use of alternative traditional materials.

It can be seen from Table 1 that some progress has been made by the brick industry on the use of alternative mineral materials other than the "traditional alternative materials". Brick works currently utilise blast furnace slag in bricks and they also undertake research with quarry fines, incinerated sewage sludge ash (ISSA), water treatment residues (WTR), scrubber waste and pottery glaze being some of those newly introduced mineral waste streams currently in use, although they correspond to single cases. Future work should take place to establish the use of the above alternative materials as common practice. Even these single cases though are expected to stimulate competition within the brick manufacturing sector.

Material related barriers (Table 2) appear to be the most apparent, which is expected as the majority of trials undertaken are lab-based except from some work scale trials that corresponded to specific commodities such as container glass. Material related constraints relate to adverse properties of the waste, such as the compositional variability, the particle size, the calorific content or low availability as well as to the properties of the end product. For instance the colour of the brick after firing may not be desirable or the presence of soluble salts found in the waste results in 'scumming' and efflorescence which makes the appearance of bricks less attractive. Nevertheless, this does not always imply that these waste materials are not suitable for use in the brick industry. For instance the incorporation of 10% (weight percentage) of paper ash fired at a specific temperature may result to high shrinkage or scumming. However, changing any of the test conditions, for example lowering the firing temperature or reducing the weight percentage of paper ash added or even performing testing with a different clay body may produce some desirable results. Although the brick industry does undertake some research on this area, it seems that it has not been rigorous enough and detailed to the level needed. The reason behind this is that the legislation in force as well as the objectives set by sustainability strategies consider as higher priority energy efficiency issues, rather than the utilisation of alternative materials. Also most brickworks own clay quarries, therefore the cost for raw materials is minor. Hence, alternative materials must provide clear benefits to the industry in order to be used.

Often the purchase price of alternative materials is high and discourages their use, even though their contribution to the end product is valuable. A case study example that provides evidence of the above is the work undertaken on the use of container glass in bricks. Glass is a fluxing agent that reduces the firing temperature in the kiln and also improves the strength of the end product. However, in order for glass to be introduced in the process, it should be of a fine particle size (80% passing 150μm). The grinding steps involved increased its final purchase price quite significantly. According to past research undertaken by Ibstock Brick during large scale work trials, the benefits shown by the use of glass (i.e. energy savings) do not off-set ompensate the price. A similar example comprises the use of Ti-oxide rich by-products that are very desirable colourants, but they are expensive to buy.

For some of the waste materials shown in Table 4 such as the incinerated sewage sludge ash (ISSA), a waste management license is required. The license application process is seen as a barrier by some companies, because the bureaucracy, costs and time delays involved complicate the initial objective.

Public perception associated with certain wastes such as sewage sludge is also considered a significant constraint, which discourages the use of the material. Overall though the perception of the public on the use of waste in bricks is not described as negative and the industry expects that public behaviour will change positively over time.

The incorporation of fine alternative materials such as quarry fines, glass and saw dust may require the installation of dust control techniques in order to comply with air pollution and health and safety regulations. Also certain arrangements may be considered essential for storing waste on site (i.e silos). For specific materials even alterations in the manufacturing process might be necessary. For instance water treatment residues and paper sludge have high moisture content. Hence, the introduction of these materials in the clay body must follow a different procedure than conventional methods. All the above examples demonstrate the barriers that the industry has to face in order to utilise waste. Along with the technical difficulties, significant investments are also required to cover the expenses of new installations and changes in the manufacturing process and often companies are not prepared to provide all these extra resources.

Mineral planning permissions for clay quarries extend for up to 30 years more, consequently as far as the clay resources are available, the use of any different materials in the brick body will only be considered for altering their aesthetic properties. Whether market demand for an end product that utilises a certain waste material will be high cannot be estimated currently as only lab scale trials have been undertaken for the majority of non-well established materials. For that reason, it is difficult also to predict if an investment in new blending, storage or processing facilities will be successful.

From the responses given by the industry, it was also highlighted the difficulty faced during testing. Deciding on the suitability of a waste material for brick making cannot take place imminently. A step by step approach must be adopted and the final decision will have to be based on the results obtained from full scale work trials. Initially some laboratory scale experimentation takes place. Commonly the user is provided with some samples of waste material plus any analytical data available describing its composition (i.e. chemical analysis). The user examines the effect on appearance and shrinkage of lab-scale samples for different substitution percentages and firing temperatures in order to evaluate the suitability of the waste material. Once the laboratory outcomes are satisfactory, a small scale trial is planned for producing a few hundreds to up to 1000 bricks. This step is quite critical as it involves the production of bricks of proper dimensions. The extrusion process and the effect of the kiln environment are also assessed. For instance, the use of abrasive materials (i.e glass) or materials with high moisture content may reduce the efficiency of extrusion. In addition, at the moment there is no lab-scale extrusion technique, which will produce bricks of saleable dimensions. The kiln firing process cannot be compared with the testing taking place in a laboratory. A kiln is normally filled with thousands of bricks, positioned in stacks, so apart from testing shrinkage and the aesthetic properties, the behaviour of the bricks not at an individual basis but overall is also examined. Again this is a critical parameter, especially for materials that present fluxing properties (i.e bone ash, glass, ISSA), because if the percentage added is too high then this may lead to adverse results (i.e. bricks may stick together or damage may be caused to the kiln). Properties such as the durability of bricks cannot be evaluated in the lab. Durability describes the long-term behaviour of bricks, and it needs to be tested in bricks produced following the manufacturing process. Once the results of the small scale trial are good, a full work scale experiment (approximately 10,000 bricks) will take place, which will evaluate all the aspects of the production and firing process. (i.e alteration to the process or new installations required). From the full scale trials a feasibility study on the economic aspects of the manufacturing process will be conducted to determine whether the utilisation of a specific waste in brick making has altered in a positive or negative way the economical equilibrium of the process.

The behaviour of brick industry regarding the use of alternative materials can be summarised in the following bullet points:

1. The industry already uses some well established alternative materials (traditionals) and an increased activity to experiment with new ones is shown.
2. The market of brick focuses mainly on facing bricks. The aesthetic properties of these products are very important
3. A sustainability strategy has been set from the brick manufacture and the use of alternative materials is mentioned.
4. Almost all companies have performed lab-scale trials with various waste materials, however only a few of these trials have progressed to utilisation.
5. Some companies are moving towards the use of alternative materials quicker than others and invest into research and new facilities. For instance Hanson building products plan to open a new plant that will focus and perform trials only on products with recycled content.
6. Overall though the progress that the sector has made is slow in comparison to other construction products.

The constraint seen for moving towards the use of waste are summarised below:

- The compositional variability of waste is a critical issue as it affects the consistency of the end product.
- Several testing trials must take place prior to use and rigorous monitoring must be established to allow the continuity of the production process.
- The majority of brickworks are clay quarries, therefore primary materials are cheap to use. Alternative materials will be considered only if they contribute desirable aesthetic properties at minimal cost to the industry.
- A waste management licence may be required for some of the waste materials.
- There is no alternative materials classification guide for the brick industry that could inform users about the advantages and disadvantages associated with their use. Different clay bodies may produce different results when using the same waste. The only documentation available comes from some WRAP funded projects that looked at specific waste streams (i.e glass).
- Companies may be required to invest on new facilities (i.e storage) or alterations in the manufacturing process in order to allow the use of alternative materials.

- The significance of non-material related barriers for “new” waste streams cannot be estimated at current stage as very little progress with small/full scale trials has been made.
- Sustainability strategies have energy efficiency issues higher on their agenda than the use of alternative materials.
- Disposal costs for inert waste are very low and they discourage recycling, although many of these materials could be suitable for use from the brick industry.

The drivers seen that could move the use of waste forward are:

- Waste represents a cheap material source. Taking into account the market competition on facing bricks, companies are required to seek continuously for new materials that could enhance the appearance of their products.
- The use of construction products with recycled content is becoming a trend, therefore the manufacturing of such products is considered essential.
- An increase in landfill tax is believed to stimulate recycling for more waste materials and some of them could find application in bricks.
- The legislation on the sustainable use of natural resources will also influence the brick manufacture and the use of alternative materials that will substitute for clay will become essential.
- Overall it is believed that the legislation in force is one of the most important drivers for the brick industry to move towards the use of waste and alternative materials.

3.3 Characterisation framework for the brick manufacture

Alternative materials that match with the categories (given in section 3.1 - Clay substitutes, Fillers, Body fuels, Colourants, Fluxing agents) of brick components are shown in Figure 6, Figure 7 and Figure 8. The component analysis diagrams have been constructed upon industry’s responses. The list of presented materials though is not limited. Other waste streams that have not been considered so far may also provide benefits to the brick industry.

The purpose of this characterisation system is to classify waste according to its contribution to the process. The properties and analytical data requirements associated with each one of these components are different. For instance for materials with the potential to be used as body fuels, the calorific content is of interest, whereas for fluxing agents the temperature they become reactive and the particle size are considered critical. Equally for colourants, the appearance of the bricks (colour, surface appearance) after firing is of importance.

The role of a single alternative material can fit in more that one of the component categories. For instance pulverised fuel ash can comprise a secondary clay substitute and body fuel, but its primary use will be filler. For that reason all materials are further categorised according to the significance of their end use into primary, secondary or tertiary potential additives.

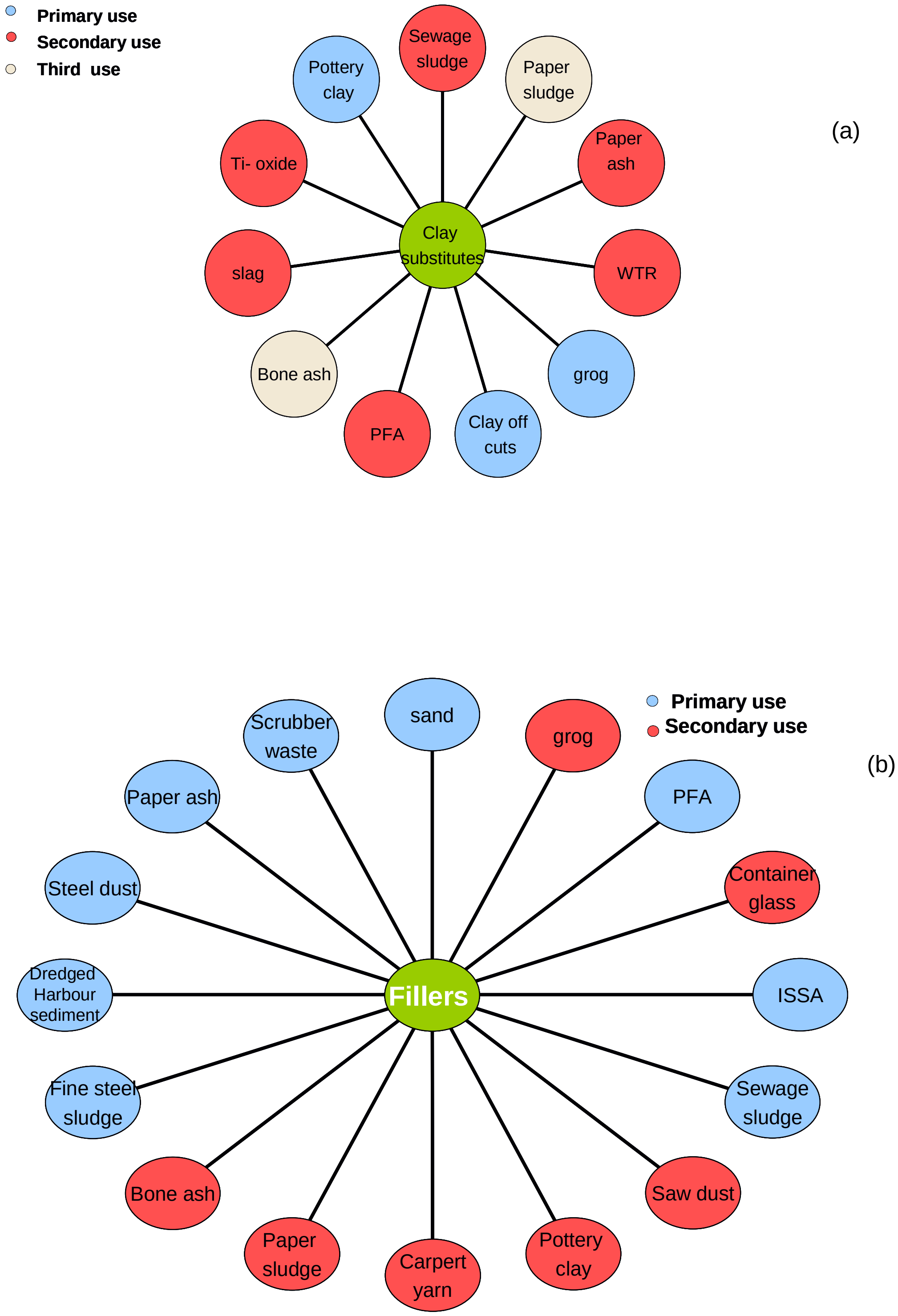

Figure 6: Brick manufacture component analysis – the potential of alternative materials to be utilised as (a) clay substitutes or (b) fillers.

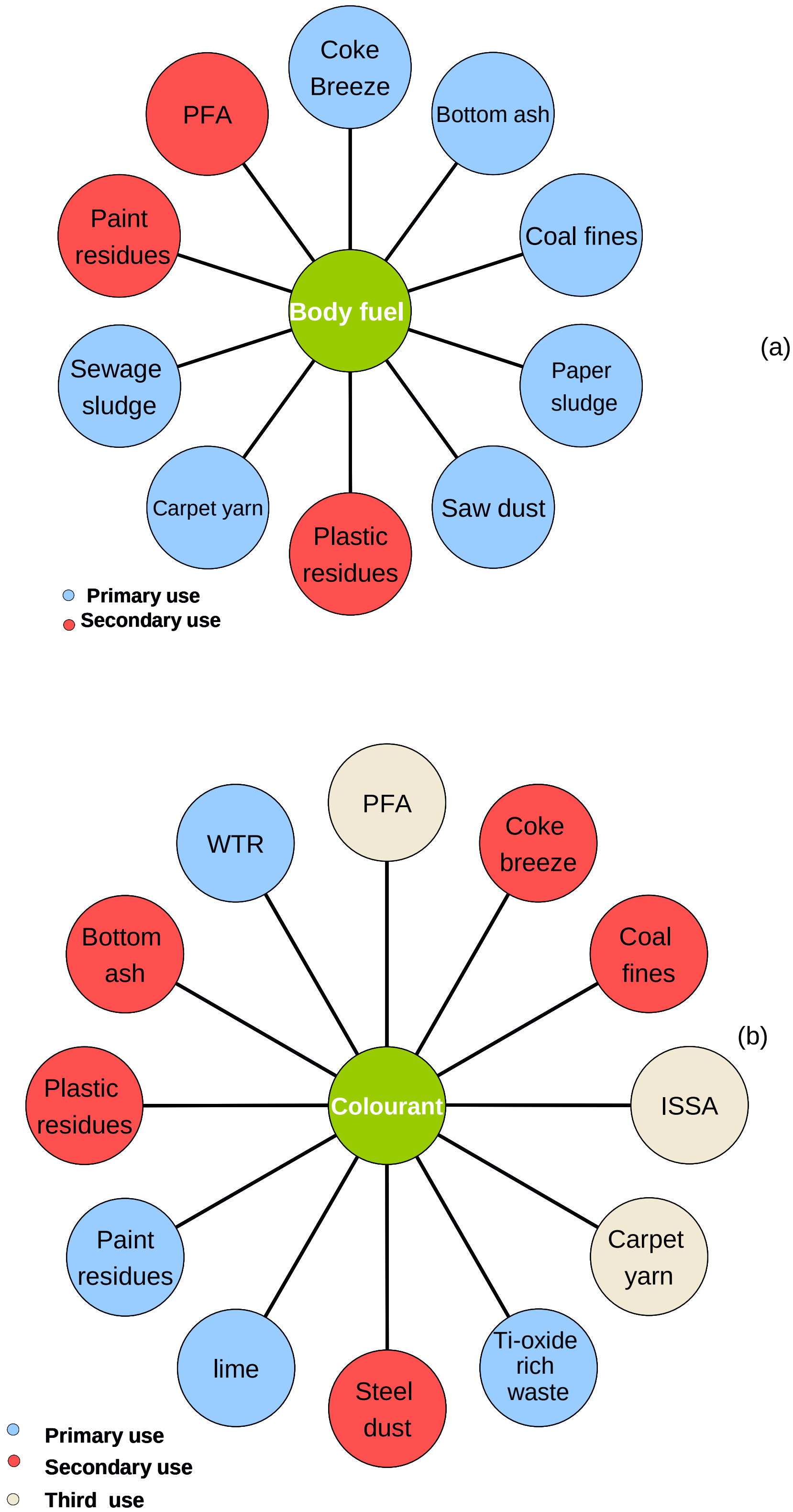

Figure 7: Brick manufacture component analysis – the potential of alternative materials to be utilised as (a) body fuels or (b) colourants.

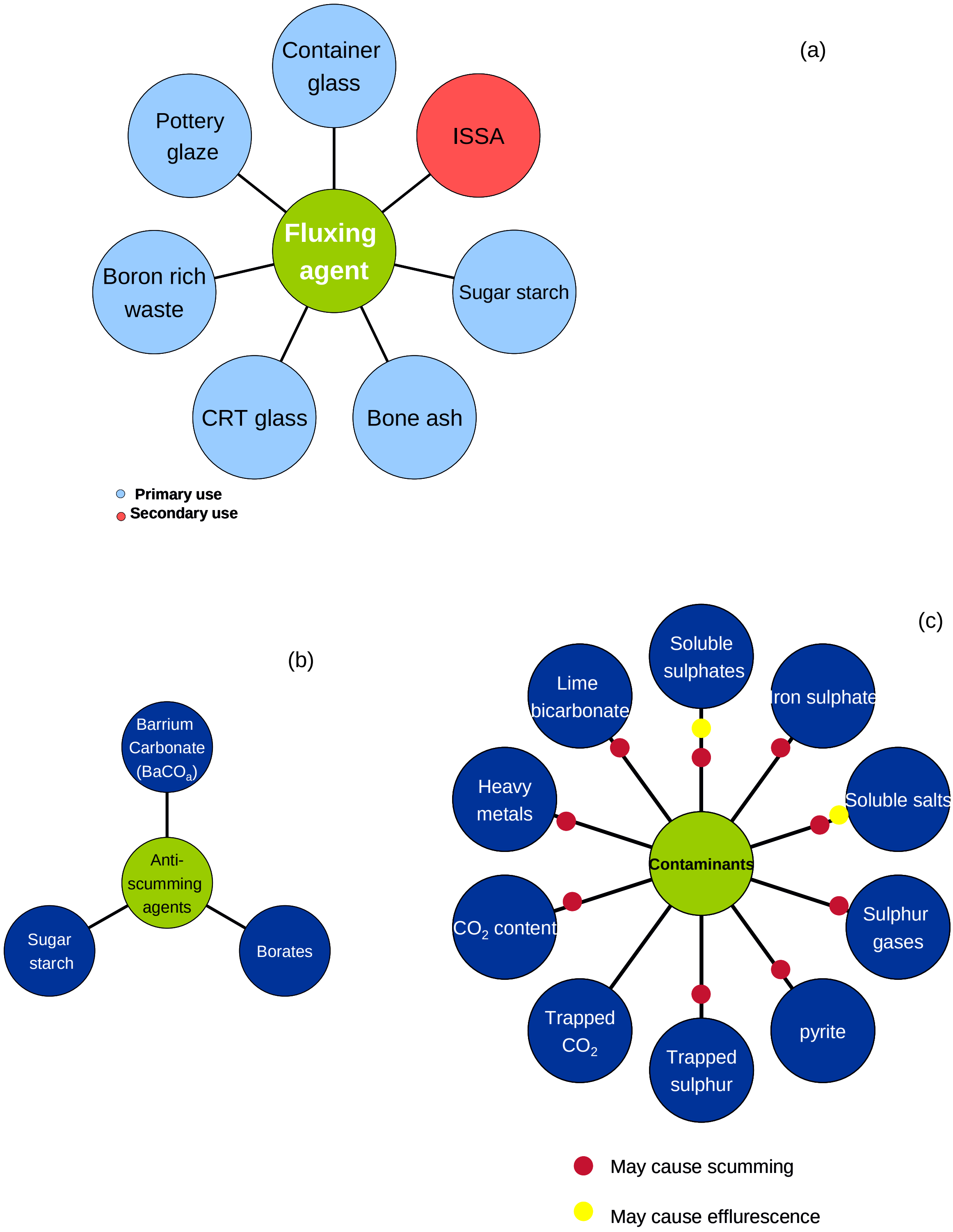

Figure 8: Brick manufacture component analysis – the potential of alternative materials (a) to be utilised as) fluxing agents; (b) potential anti-scumming agents (c) contaminants in brick making.

Figure 8 shows two additional categories that look at contaminant associated with bricks and anti-scumming agents. Scumming and efflorescence is caused due to the migration of soluble elements to the surface of bricks. Figure 8 (c) displays all the different constituents that can result to scumming and efflorescence. Trapped CO_2 may also comprise a problem, as it can cause explosion of bricks that cannot release it and cause damage to the kiln.

The effect of scumming is controlled by the use of additives such as barium carbonate (~ 1%). This agent however is expensive to use and its use is commonly limited to cases that cannot be avoided. Alternative materials such as sugar starch and borates could substitute for barium carbonate as anti-scumming agents.

The presented characterisation framework is expected to increase awareness on the particular requirements and limitations of the brick industry. Waste producers could use it as a guidance tool to determine the qualities of their waste, the benefits that it is expected to bring to the process and to identify the type of analytical data that are useful to the user during initial communication. Providing useful characterisation data to the waste user during these first contact stages could speed up the exchange process and build up a positive relationship between the involved parties. Waste users could also benefit from the components analysis diagrams by identifying new alternative materials that have not been trialled so far. In passive waste exchange systems a description of the waste according to the presented framework could provide extra hints of its potential end uses. Finally it is believed that workshops dedicated to specific industry sectors such as the brick manufacture could further stimulate interactions, educate waste producers of the characteristics of the sector and develop successful waste exchange matches.

4. Guidance on assessing alternative raw materials for the

4.1 Waste exchange and the brick manufacture

A generic model of waste exchange (presented as a separate report undertaken by this project - *Waste Exchange and Industrial Symbiosis*) suggests that in order for waste exchange to be successful, the mutual contribution of each party, namely the waste producer and user is required. During the initial stage of the exchange process both parties must provide adequate characterisation information for a match to evolve.

However from interviews held with the industry it was found out that the dynamics of the exchange process are mainly defined by the waste user. The brick manufacturer becomes the central player of the exchange process and the waste producer is asked to follow the requirements set by the user. The waste producer is commonly unaware of the type and detail of information required by the brick manufacturer. This is not the case though for the waste user who commonly knows what benefits can be seen from the use of a specific waste.

During initial contacts, the waste user is provided with samples and any available characterisation information related to the waste. The relevance of the information is evaluated by the user and the waste producer is informed about any additional analytical data required. According to the brick industry, the data on hold by waste producers relate to landfill (i.e Waste Acceptance Criteria). The relevance of these data though to waste users is often very little. Additional analysis tests are commonly performed by the waste user or the broker if involved.

Laboratory experimentation investigates various substitution rates of waste at different firing temperatures. If results are desirable, then testing progresses with small and full scale work trials. Before moving to the next step of experimentation, the benefits and barriers seen are taken into account. Small and full scale trials are only performed for commodities that exhibit a great potential for utilisation (business case reviews). Again if the investigation outcomes from full work scale trial are satisfactory, for instance if the properties of the end product are desirable and the economics of the process are also beneficial then active engagement between the waste producer and user take place (i.e a contract), which leads to successful waste exchange.

Contacts with waste producers are developed either through the use of brokerage services or by direct communication. Brokerage specialised on the ceramic sector, such as Akristos is found useful by the brick industry. Specialised brokers are aware of industry's needs and they can provide contacts with waste producers that have in hold valuable alternative materials. Also they can assist the exchange process by offering guidance and by undertaking all the intermediate steps of waste exchange (i.e check on duty of care documentation, provide laboratory testing etc) and this way they can speed up the process. The brick manufacture does not count completely on brokerage services. Very often they develop their own contacts with other industries and the NISP workshops (two of which formed part of this project) have been found useful for increasing awareness of waste streams that can become available regionally.

4.2 Future Developments

The types of waste exchange identified for the brick industry are the:

- Type I: One type exchanges that utilise a waste steam until its end-of-life, such as the use of town ash and colliery spoil.
- Type II: Companies such as Hanson and Ibstock bricks may utilise waste produced from other sectors of the same firm (i.e Hanson concrete, Forticrete)
- Type III: Utilisation of waste from local companies (i.e fly ash from local power station). As mentioned earlier in this report, the cost of raw material used for bricks is low and in order for alternative materials to compete, their cost must be kept low as well. Therefore transport becomes a significant barrier for the use of alternative materials and local sources should be exploited.

The complete description of the different types of waste exchange is provided in *Waste Exchange and Industrial Symbiosis* undertaken as part of this project. The waste exchange model approach that fits better to the heavy ceramic industries is that of green twinning. A good example of green twinning is the use of various traditional alternative materials as body fuel such as the coke breeze, town ash and coal fines depending on the local availability of resources.

5 References

Brick Development Association (1999) A sustainability strategy for the brick industry. *URL<http://www.brick.org.uk/publications/Sustainability.htm>, Access date:[10/12/2006].* UK.

British Geological Survey (2007). Mineral Planning Factsheet - Brick Clay.: URL<http://www.mineralsuk.com/britmin/mpfbrickclay.pdf>. Access date:[16.10.2007].

Communities and Local Government (2007) Brick clay. Mineral Planning Factsheets. British Geological Survey

DTI (2007) Draft strategy for sustainable construction – a consultation paper July 2007. URL<http://www.berr.gov.uk/files/file40641.pdf>, Access date:[24-08-2007].

Environment Agency (2007) Waste Protocols project. URL:[http://www.environment-agency.gov.uk/subjects/waste/1019330/1334884/?version=1&lang=_e]. Access date:[24.08.2007]

Petavratzi E., Barton J. (2006) Characterisation of Mineral Wastes, Resources and Processing Technologies.- Integrated waste management for the production of construction materials -Interim Report - Literature Review, Methodology and Database development - Case study on the utilisation of alternative materials in the ceramic products sector". University of Leeds, Leeds.