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

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Industry Sector Study:

Mineral wool insulation

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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

This report describes the results of an assessment of the role of alternative raw materials derived from mineral wastes in manufacture of mineral (or stone) wool. The report reviews the manufacturing processes and markets for the material, sustainability issues in the sector, and the utilisation of alternative raw materials. It also describes the key properties that are required of the 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.

The report focuses on mineral (stone) wool products. Glass wool (which requires high purity feedstocks) and organic insulation are touched upon in the context of the demand for insulation products, but otherwise are beyond the scope of this document. Furthermore, glass recycling is well covered by the Waste and Resources Action Programme (WRAP)[1], [2].

2. The mineral wool manufacturing sector in the UK

2.1Process overview

Mineral wool (or stone wool) is a non-metallic, inorganic product manufactured using stone/rock (volcanic rock, typically basalt or dolorite)[*] together with blastfurnace or steel slags as the main components (typically 97%). The remaining 2-3% organic content in the product as sold is generally a thermosetting resin binder (adhesive) and a little oil.

In the manufacture of mineral wool insulation, rock material and two slag materials - (blastfurnace slag and steel slag) are melted in a cupola furnace at approximately 1500°C. The two types of slag act as a flux to help the molten rock flow and lower the melting temperature. ‘Formstones’ are also added; these are manufactured “briquettes” composed of mineral wool process and product waste, processed by rod-milling the waste into dust and binding it together with binders such as starch and lime. The fuel used has a high calorific value and is usually coke. The molten mixture is spun to give a mineral wool with a fibre-like structure. Manufacturers are also prepared to consider raw materials to provide alternative sources to primary rock, flux or fuel [3]. The production process for mineral wool insulation is illustrated in Figure 1. The various inputs to the process are shown in Figure 2.

[*] Basalt, dolerite and gabbro are all naturally occurring rocks with broadly similar chemical and mineralogical composition, differing mainly in the grain size of the minerals.

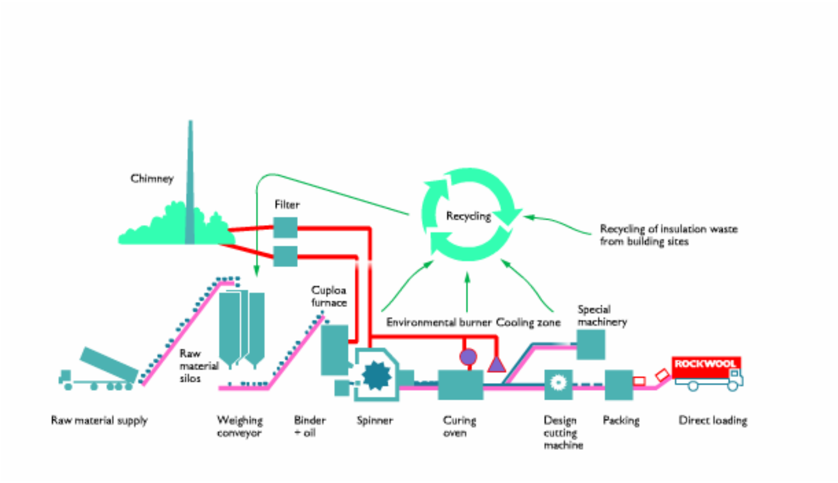


Figure 1: Schematic of the manufacture of mineral wool (source Rockwool® website)

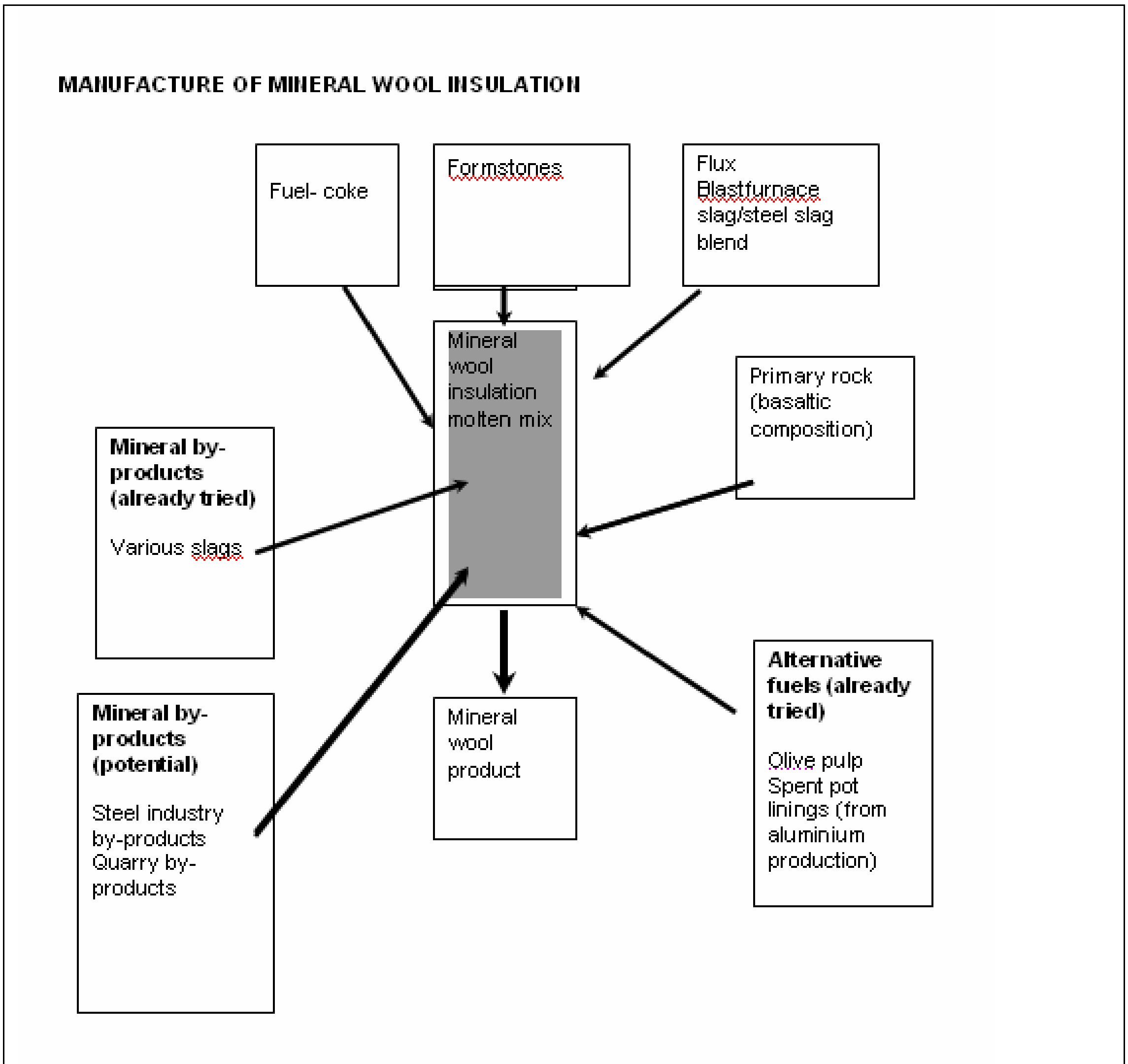


Figure 2: Characterisation Framework on the utilisation of alternative raw materials in mineral wool manufacture

2.2 Products and markets

Mineral wool can be manufactured to many different densities to give varying properties, formed into shapes and faced with a variety of sheet materials. Products range from loose material used for the injected insulation of cavity walls, slabs for walls and rolls for loft insulation through to pre-formed and faced pipe sections (laminated matting).

Insulation is used to save energy, combat noise, reduce the risk of fire and protect property and life in the event of fire. The main drive currently is to reduce energy use in buildings, with a recently increased emphasis on acoustic insulation, particularly of floors and party walls. Many products cover all uses – i.e. they are effective as thermal and acoustic insulation, with fire retardant/ prevention properties.

Insulation is used for:

Cavity wall insulation

- built into a new building by design, or retro-fitted in existing buildings (as mats, board or blown)

Solid wall insulation

- internal products include flexible thermal lining, thermal boarding (plasterboard with backing of insulation) or fibre based, though less popular due to thicknesses required
- external products – polymer-based boards generally used (phenolic) on outside of properties, which are then rendered/ finished to give 'normal' appearance

Structural Insulated Panels (SIPs)

- manufactured from either a timber or steel frame, usually with a polyurethane foam or mineral wool core

Loft/Roof insulation

- mats, board or sprayed

Flat roof insulation

- usually as integral boards
- Insulating heating systems and hot and cold water services (ducting and pipe work)
- several manufacturers offer tailored products suitable for ducting and pipe work, in both polymer-based materials and in mineral wool.
- The market demand for building insulation in general is met by many products. These can essentially be classed into three main types – inorganic (e.g. mineral wool) fossil organic (e.g. polyurethane) or natural organic (e.g. cellulose). Examples of the main types of insulation types and some of the main manufacturers are given below:

Inorganic

Mineral wool – (UK manufacturers: Rockwool®, Knauf)

Rockwool manufacture utilises slags derived from metals smelting as part of their recycled content. They also recycle production waste. Rockwool® have standing agreements with large industrial clients, to recover post-consumer Rockwool product under a standard maintenance contract for industrial applications.

Glass wool – (UK Manufacturers: Saint Gobain, Knauf, Superglass)

Glass wool utilises a high percentage of post consumer recycled glass as recycled content. Manufacturing waste is also recycled. The slightest variation in feedstock composition can affect fibre length of product so there is limited potential to incorporate by-products or wastes other than clean recycled glass.

Organic
Examples include polyurethane, PU/polyisocyanurate PIR, phenolic, expanded polystyrene EPS, extruded polystyrene XPS , cellulose fibre, sheep's wool, hemp fibre.

A WRAP guide to specifying construction products with recycled content, includes insulation products for roofs, floors and walls by manufacturers such as Superglass and Isowool that contain recycled or by-product materials [1]. The products have mainly been glass wools (so utilising secondary sources of container or window glass) or polystyrene products (recycling the thermoplastic polystyrene). They do not appear to have included the secondary materials utilised in the manufacture of rock wool-type insulation, therefore they are beyond scope and are not considered here.

The market size for insulation generally is expected to increase. According to figures derived from the Department for Communities and Local Government, the volume of insulation products installed in buildings each year in the UK is approximately 14 million cubic metres. Figure 2 shows the breakdown of the insulation market by value. It is assumed that the 'value' breakdown is representative of the volumes used, since thinner products are likely to be more expensive. The market is dominated by mineral fibre, a position that is expected to continue. There will therefore be an increasing demand for the raw materials for mineral wool manufacture. Key influences on the demand for insulation are given in the roadmap (Section 5).

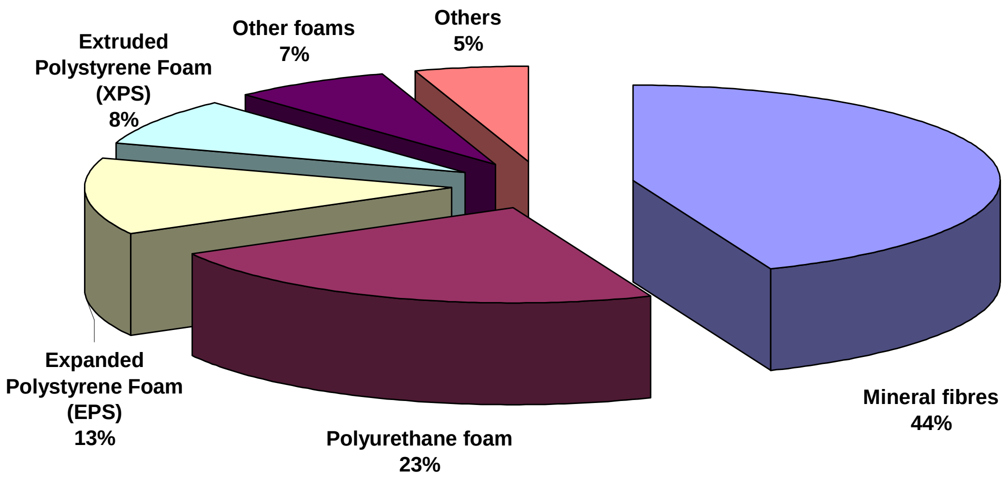


Figure 2: Insulation Market Value broken down by insulation type (AMA Research)

2.3 Sustainability issues and mineral wool manufacture

In a comparison of all common insulation materials, mineral wool (made from rock and slag), (together with glass wool) is one of the best performers, scoring a summary rating of "A" in the Green Guide to Specification[†]. However, the Green Guide is regularly updated and the

[†] The Green Guide to specification gives an assessment of construction materials and elements based on their environmental impact over their life cycle. A is currently the highest rating. Indicators include greenhouse gas emissions, minerals extraction and waste generated.

ratings become more difficult to achieve as industries' environmental performance improves. This provides a strong driver for industries to improve their environmental performance.

Mineral wool generates very little manufacturing waste (a few %), as materials can be fed back into the manufacturing process. There is virtually no installation waste when it is blown in place on site and ~5%waste from rolls depending on the nature of the installation.

If mineral wool waste from construction and refurbishment could be recovered relatively contaminant- free, it would be possible to return it to the manufacturing process to be recycled as an alternative to landfill disposal. It is technically feasible to operate a closed loop recycling system, if sufficient collection and transport infrastructure were developed. Rockwool® offers a take-back service to some of its major industrial clients, who have regular maintenance schedules necessitating replacement of the product[4]. Such material is generally received in a 'clean' state and so can be recycled back into the original material feedstock. Rockwool® would like to increase the scope of this service, but stresses that levels of contamination would be an important factor for consideration. Alternative recycling options are also sought.

Specific examples of resource efficiency in the manufacture of mineral wool by Rockwool® are:

Reuse of by-products from other industries
Currently, between 20 and 30% of the total furnace charge is made up of by-products from the steel-making industry.

Reuse of off-cuts from the Rockwool production process
Off-cuts from cutting and shaping Rockwool products during production are recycled directly back into the manufacturing process. Currently, off-cuts and similar 'directly recycled' material account for approximately 10% by weight of the finished product.

3. Alternative raw material usage in the mineral wool manufacturing sector

The use of alternative raw materials derived from industrial waste is already well established in mineral wool production. A major manufacturer of mineral wool (Rockwool®) is keen to promote this aspect of their environmental credentials and offers to take industrial waste as a service‡.

In common with the manufacture of Portland cement, the raw materials for mineral wool are proportioned by the manufacturer to give an overall oxide composition that lies within a defined compositional envelope (Table 1). At present, for mineral wastes to be suitable, these have to be relatively large in particle size (25 mm or larger) to avoid interference with the kiln operation. In their plant in Bridgend, South Wales, Rockwool® have utilised a variety of slags and igneous rock sources of basic composition (ie basalt, gabbro, dolerite/diabase). The ingredients can include both inorganic wastes (such as slags and sands) and combustable waste materials (to provide fuel). Some of these materials have been derived from legacy slag tips derived from historical operations, which could be suitable for use[5].
The ability to handle and process materials with particle size < 25 mm would potentially open up a wider range of fine materials of the appropriate composition and this is currently being looked at by manufacturers. Potential candidate materials include steel slag fines, blastfurnace slag fines and quarry dusts derived from rocks of basalt/gabbro/dolerite composition.

‡ Rockwool brochure: "from waste to resource"

3.1Key requirements

Key requirements for alternative raw materials for mineral wool manufacture are as follows:

a) Flux and rock: chemical composition appropriate to meet the required composition envelope when combined together. A variety of slags and igneous rock sources of basic composition (ie basalt, gabbro, dolerite/diabase) are likely to be suitable.
b) Fuel: solid material with sufficient energy content but whilst keeping overall composition within required composition envelope. Materials with low organic content are not likely to be suitable.
c) Particle size of 25 mm or larger to avoid interference with the kiln/cupola operation.

Table 1: Typical compositions of blastfurnace slag, steel slag and basalt rock (% by weight)

Oxide	**Mineral wool: target composition (source Rockwool®)**	**Blastfurnace slag**	**Steel slag**	**Basalt composition***
SiO_2:	40.3 – 43.4 %	35%	10-12%	46.2-51.4
Al_2O_3:	17.5 – 20.3 %	14 %	1-2%	10.4-18.9
TiO_2:	0.6 – 2.6 %	-	0.5%	0.8-2.5
Fe_2O_3:	6.1 – 8.4 %	-	27 -31%	15.8-21.2
CaO + MgO	23.7 – 27.7 %	48 %	47-50%	15.6-30.3
Na_2O + K_2O	1.3 – 4.3 %	-	-	1.8-3.7

*(source of basalt compositions: Nockolds, S.R, Knox, RB and Chinner, G.A. Petrology for students (Cambridge University Press, 1978))

Table 2: List of alternative materials that substitute and potentially substitute virgin raw materials in mineral wool (key: Si=SiO_2, Ca=CaO, Al=Al_2O_3 and Fe=Fe_2O_3)

Recycled material	Progress	Ingredient	Comment
Production waste (mineral wool)	Routinely used	Si + Al + Ti + Fe + Ca + Mg + Na + K	Closed loop recycling routinely conducted with production waste as an ingredient in the formstone component of the kiln feed
Post-consumer mineral wool and ceiling tile waste	Routinely used	Si + Al + Ti + Fe + Ca + Mg + Na + K	Take-back schemes are available. Amounts expected to increase as construction site management plans become compulsory.
Recycled mineral wool from demolition waste	Not in use	Si + Al + Ti + Fe + Ca + Mg + Na + K	Collection facilities do not exist. Concerns about contaminants and segregation on construction sites
Teeside (old blastfurnace) slag	Trials	Si + Al + Ca + Mg	Trialled but chemistry inappropriate
Alpha (steel/converter) slag	Trials	Fe + Ca + Mg + Si	Trialled but chemistry inappropriate
Celsa (steel/converter) slag	Trials	Fe + Ca + Mg + Si	Trialled but chemistry inappropriate
Olive pulp pellets	Trials	C	Trialled but chemistry inappropriate
Spent pot linings from aluminium smelting	Trials	C	Successful trial. Increased fluoride emissions would require scrubbers to be fitted to the plant. Nevertheless, still economically viable. Material does not contribute chemically to the final product
Shepton Mallet Basalt	Trials	Si + Al + Ti + Fe + Ca + Mg + Na + K	Trialled but chemistry inappropriate
Mendip Basalt	Trials	Si + Al + Ti + Fe + Ca + Mg + Na + K	Trialled but chemistry inappropriate
Gabbro (Basalt composition)	Trials	Si + Al + Ti + Fe + Ca + Mg + Na + K	Trialled but chemistry inappropriate
Steel slag fines	Not in use	Fe + Ca + Mg + Si	Particle size inappropriate
Other steel-works wastes (eg electric arc furnace dust)	Not in use	Various	Particle size inappropriate

3.2Substitute materials

Mineral wool manufacture would typically involve the use of bulk sources of steel slag and blastfurnace slag from the steel works nearest the production plant and primary rock. Substitute materials known to have been trialled, or currently used in mineral wool manufacture include those shown in Table 2.

Alternative materials can be used as partial substitutes for slag (flux), rock or fuel. Several trials have been undertaken to illustrate how alternative materials can substitute to provide sources of Si, Al, Ti + Fe + Ca + Mg + Na + K.. An oxide analysis using techniques such as x-ray fluorescence can be used to assess suitability.

The rationale behind the increased use of alternative fuels is found in industry's objectives towards sustainability, in combination with the increasing prices of conventional fuels. The most suitable fuels have a high carbon content. One example trialled is spent pot lining (the carbon cathodes from primary aluminium smelting).

Table 3 presents industry's current response regarding the utilisation of alternative materials plus the potential benefits/barriers, as well as the types of analysis required during the waste exchange process. The majority of the barriers to the use of materials as partial substitutes to the usual sources of flux or rock are generally "material –related". In general, the amount of alternative material that could be incorporated, whilst meeting the requirement of the composition envelope, was not commercially worthwhile.

The Green Guide to specification and BREEAM, both of which provide an assessment of environmental impact of buildings or components, include within their assessment 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 impacts positively in this regard.

Table 3: Classification of industry's response regarding the utilisation of alternative materials in cement's recipe. (Key; Numbers shown in benefits/barriers; Categories of benefits/ barriers➔ MR=material related, EC=economic; ranking system shown in barriers➔ 1= significant, 2= important, 3= less important, 4= future work will define significance)

Recycled/ Replacement material	**Component Type**	**Potential Benefits**	**Potential Barrier**	**Analysis**
Teeside slag	Slag/ flux	Cost saving over usually materials used 2EC	Chemistry not appropriate 1MR	Oxide analysis (XRF), particle size
Alpine slag	Slag/ flux			
Celsa slag	Slag/ flux			
Olive pulp pellets	Fuel			Carbon content
Spent pot linings from aluminium smelting	Fuel	Alternative to coke – cost saving 2EC	Successful trial but increased fluoride emissions requires scrubbers to be fitted. Still economically viable 3MR	
Shepton Mallet Basalt	Primary rock	Seeking secondary/ alternative source of supply. Potentially cost savings also. 2EC	Chemistry not appropriate with other ingredients 1MR	Oxide analysis (XRF), particle size
Mendip Basalt	Primary rock			
Gabbro (Basalt composition)	Primary rock			

3.3Characterisation Framework

Manufacturers will typically use a spreadsheet to calculate the quantities of the raw materials required to go into the melt. The ratio of the material components are added to the cupola in a precise way depending on their chemical composition, which is the most important dictating factor for the use and suitability of a material. General tolerance limits are given for compounds SiO_2, Al_2O_3, TiO_2 and Fe_2O_3, however these need to be achieved based on the overall combination of the raw materials used, rather than based on an individual component (Table 1). E.g. If the level of silica is reduced in one component, it will likely need to be compensated for (i.e. increased) in another component.

3.4Standards and protocols

There are a variety of product standards for mineral wool. However, the suitability of raw materials (rock and flux) for the manufacture of mineral wool insulation are governed by company-specific quality and acceptance procedures.

WRAP and the Environment Agency have recently published a quality protocol for blastfurnace slag. The Protocol re-classifies blastfurnace slag as a by-product, giving clarity over the materials standing within waste regulations and bringing clarity to its use[6]. A British Standard specification for blasfurnace slag as aggregate is also available [7]. The material is produced in a closely controlled process for the smelting of iron ore. Steel slag is processed and weathered prior to sale for use, principally as a construction aggregate[8]; this material is currently classified as a waste.

The primary rock materials used in the manufacture of mineral wool are typically igneous rocks of basaltic composition. Standard methods are available for classifying rock type exist [9] although a full oxide analysis will be critical to establish fitness for purpose.

4. Guidance on assessing alternative raw materials for the mineral wool manufacturing sector

4.1Waste exchange

Information on the approach of mineral wool manufacturers to waste exchange has been sought. The industry actively seeks partnerships with waste producers for sources of materials[3].

For example, the Rockwool plant at Bridgend in Wales has a relationship with Arena Network, who manage the Materials Action Programme Industrial Symbiosis Scheme (MAP-IS) in Wales (equivalent to the National Industry Symbiosis Programme, NISP) [10] http://www.arenanetwork.org/mapis/. The Arena organisation provides material oxide compositions to Rockwool relatively frequently to see whether wastes can be incorporated into their manufacturing process. Some of those that have been trialled recently are detailed in the tables above. Viable commercial arrangements generally involve a fee which is less than the gate fee for the alternative material concerned.

The barriers to the use of alternative by-products forward are:

- Location of raw materials relative to plant may make waste exchange uneconomic
- Fine particle size by-products cannot easily be accepted into the process
- Only raw materials within certain compositional envelope can be accepted

The drivers seen that could move the use of alternative by-products forward are:

- Landfill tax escalator
- Customer product demand
- Collection systems for mineral by-products, refurbishment waste etc
- Shareholder demands and corporate social responsibility policies

Criteria for partnership with raw material suppliers are likely to include:

- Guaranteed quantities and sizes of deliveries
- Content and quality of deliveries
- Agreement to a fee or co-financing of waste handling costs (including chemical analysis, test runs, approvals, any additional environmental or safety measures).

4.2Future developments

As mentioned in Section 1, the demand for insulation materials is expected to grow significantly. With its good environmental credentials, mineral wool insulation is expected to play a key role in meeting this demand. The mineral wool industry is already well placed and already accepts alternative raw materials. A breakthrough in processing to allow the incorporation of rock and flux with relatively small particle size would open up possibilities for a whole range of alternative raw materials derived from minerals extraction and metals smelting.

5. Overview roadmap for utilising alternative materials in the mineral wool manufacturing sector

5.1Industry drivers

The following influences will be key to the insulation manufacturing industries over the next 5-10 years:

- The UK government has introduced the requirement for a “Sellers Pack” to be available for all homes for sale – called the Home Information Pack (HIP). The HIP will incorporate the house’s energy performance certificate giving its energy rating, together with information concerning local searches, property information, etc. Although there may be no regulatory requirement to upgrade energy performance standards for existing houses, the UK government believes that the needs for the HIP will stimulate the householders to upgrade insulation and other energy efficiency measures to be able to quote a better Energy Rating for their house on sale.

- Government estate committed to 30% reduction target for energy

- Concerns about rising costs of energy and energy security

- The Code for Sustainable Homes is a legislative requirement which sets requirements for all elements of house construction. This includes a requirement for materials and construction waste based on the BRE Green Guide Rating[12] for key elements. It will be important for manufacturers to maintain and improve the environmental performance of their products to meet the Code requirements.

- Compulsory site waste management plans (SWMP): as a minimum, construction sites over a certain size will be required to write and implement a site waste management plan to address resource efficiency. A voluntary code has already been introduced. The introduction of compulsory SWMP's is expected to increase the demand for take-back schemes.

- Increase in new build activity (Government target of an additional 200,000 houses per year in key areas by 2016)
- Rising energy prices
- Life Cycle Assessments of buildings and components through the Green Guide to Specification and BREEAM.
- Encouraging RMI (refurbishment, maintenance and improvement) Grants available to encourage retrofit of insulation

Other key industry drivers for the built environment that impact on the insulation industry are set out below:

Technological

- Modular build and off-site construction

Environmental

- Pressure on waste disposal and for recycling
- Scarcity of key construction materials

Economic

- Increased global competition for resources
- Rising materials costs

5.2Roadmap

The main manufacturers of mineral wool and glass wool in the UK are:

Mineral wool insulation: Rockwool, Knauf
Glass wool insulation: Saint Gobain, Knauf, Superglass

There is no clear overall industry sustainability strategy for the insulation industry as a whole. The trade association "Thermal Insulation Manufacturers and Suppliers Association" (TIMSA) [11] represents all the major manufacturers and many of the suppliers and distributors in the UK thermal insulation industry. Its members include manufacturers, designers installers and suppliers of all aspects of insulation and ancillary products such as adhesives. Unlike other industries such as the cement industry, there is no common policy for sustainability. However, the main producer of mineral wool (Rockwool® and Knauf), individually have strong sustainability agendas. The insulation industry is keen to stress the importance of insulation and its impact on the energy performance of buildings and greenhouse gas emissions. As mentioned earlier, there is little potential to recycle mineral wastes into glass wool insulation products.

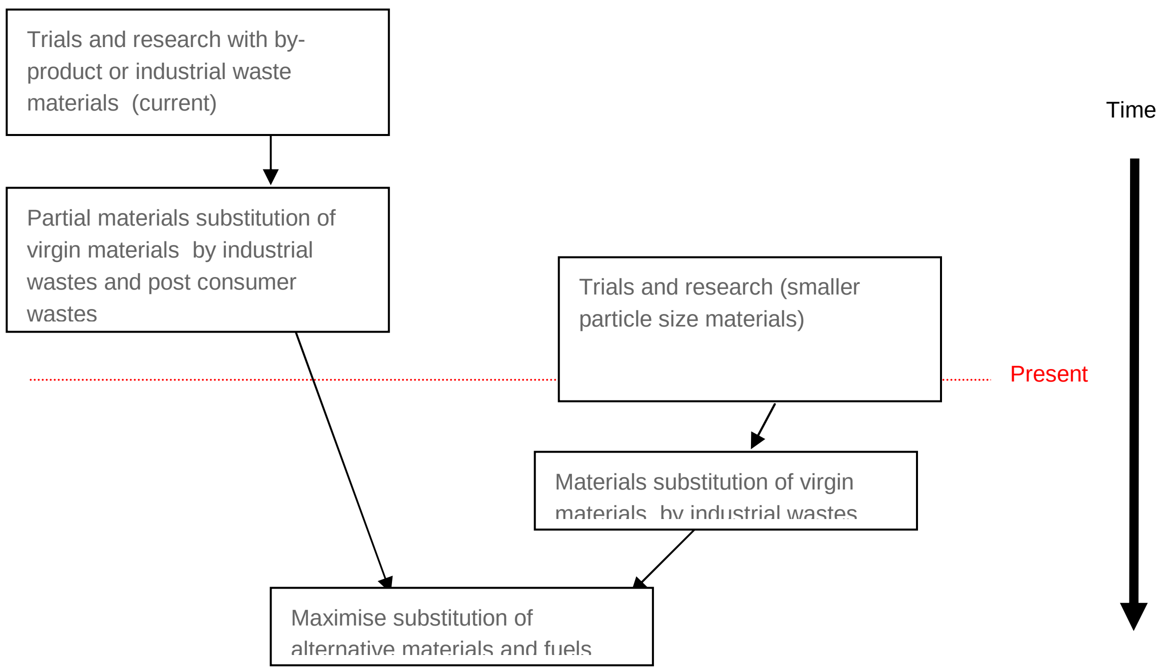
The following sustainability measures are available to the mineral wool manufacturing industry to meet their sustainability agenda:

Sustainability
o Use of residual products from other industries (leading to partial substitution of

	primary materials by alternative raw materials and fuels with a lower carbon footprint)
o	Higher utilisation rates if alternative raw materials can be achieved through logistics, provision of continuous supply of consistent properties and quality, which can create a demand
o	Company policies to make use of recycled materials in products and to minimise waste

The manufacturers are already implementing many of these measures. The challenge remains to maximise the substitution of virgin materials by continuing to trial alternative materials and to identify and exploit new sources of these materials. This is represented in the following roadmap (Figure 3).

Figure 3: Roadmap on the utilisation of alternative materials in mineral wool insulation



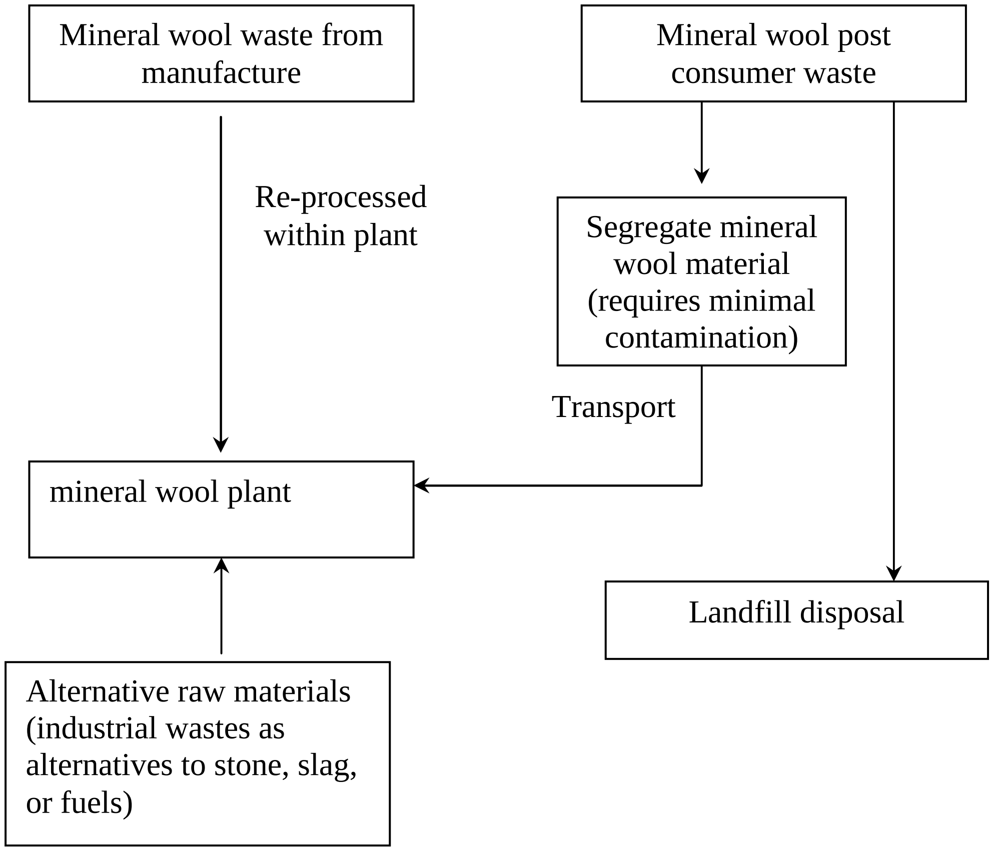


Figure 4: Alternative resources for mineral wool manufacture

Potential benefits of alternative raw materials in mineral wool insulation
o Material related: substitution of raw materials o Economic: profit through charge of a disposal (“gate” fee), reduced cost of fuels o Environmental: Reduced CO_2 emissions, conservation of natural resources, recycle combustable residues o Organisational: maintain industry’s environmental profile for green products, better flexibility in raw materials sourcing o Legal: Good practice may cause wastes to become by-products (through quality protocols) o Social: cleaner environment, waste management, less quarrying

Potential barriers to alternative raw materials in mineral wool insulation
o Material related: Logistics, continuity of supply (particle size, composition), geographical proximity, variability, undesirable properties, health and safety issues o Economic: Additional costs of handling, testing, trials, storage, processing requirements, monitoring, licensing, transport o Environmental: increased emissions o Organisational: Additional installations, corporate responsibility o Legal: Licensing, hazardous waste, waste transfer and storage o Public perception of the utilisation of wastes

Future work:
1) Quality protocols: preparation of quality protocols for the utilisation of alternative raw materials such as steel slag (protocol for blastfurnace slag has recently been introduced) 2) Improved processing to allow greater incorporation of mineral waste with small particle size.

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