Office of the Deputy Prime Minister
Creating sustainable communities

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Mineral Planning Factsheet

Natural hydraulic limes

*This factsheet provides an overview of the raw materials used to manufacture **Natural Hydraulic Lime** in Britain. It is one of a series on economically-important minerals that are extracted in Britain and which are primarily intended to inform the land-use planning process. The factsheet differs from others in the series in that it covers, in necessary technical detail, a specialist product, which recently ceased being produced in Britain, as a result of the refusal of a planning application. There remains a small, but important market for Natural Hydraulic Lime, notably in the repair of historic buildings.*

Hydraulic Limes are traditional construction materials and were the primary hydraulic binders used in mortars prior to the development of Ordinary Portland Cement (OPC) in 1824. Examples of their use date back to at least Roman times. The term 'hydraulic' describes material that will set and harden under water. The process by which limes set is due to chemical hydration (reaction to form strength-developing compounds), with additional strength being gained by the carbonation (absorbing atmospheric CO_2) of the free calcium hydroxide present.

In the last 100 years, the terminology that describes lime products used in building and restoration has become confused. Hydraulic limes as defined in BS EN 459-1:2001 the current British Standard *Building lime — Part 1: Definitions, specifications and conformity criteria*, fall into two types, 'Natural Hydraulic Limes' and 'Hydraulic Limes'. This factsheet covers the production of **Natural Hydraulic Limes.** Natural Hydraulic Lime (NHL) is produced from a naturally-occurring raw material rather than by blending Calcium Lime (CL) with a pozzolanic material as used in the production of Hydraulic Limes (HL). Pozzolanic materials (or pozzolans) consist mainly of reactive silica (SiO_2) and alumina (Al_2O_3). When finely ground and mixed with lime, and in the presence of water, they react with the dissolved calcium hydroxide [$(Ca)OH)_2$] derived from the lime to form strength-giving calcium silicate and calcium aluminate compounds. (The term is derived from Pozzuoli in Italy where volcanic ash was used in mortar in Roman times).

NHLs are produced by calcining argillaceous (clayey) or siliceous limestones, which are then reduced to a powder by the addition of controlled amounts of water (slaking), with or without the need for further grinding.

Both NHL and HL limes can produce hydraulic lime mortars and hydraulic lime renders/plasters of similar physical properties. However, there is a distinction between NHL and HL in the market place, especially when used in the repair and restoration of historic buildings. In this specialised, and very small market, NHLs are viewed as being the 'true' and 'authentic' hydraulic limes and there is, therefore, a tendency for these end-users to specify NHLs only.

Demand

Natural Hydraulic Limes are used as an alternative to cement-based binders in mortars and renders, either in new building or in the repair and maintenance of historic buildings, such as repointing. A substantial part of the nation's historic building stock was constructed with NHL. There is, therefore, an established market for these materials in conservation work. NHL mortars combine some of the benefits of a cement-based mortar (setting time and strength development) with those of hydrated lime (see box on next page) mortars.

Natural hydraulic limes

Definitions

The use of lime and lime mortars, being traditional construction materials since Roman times, have over the years resulted in a diverse and sometimes confusing vocabulary. To assist with the understanding of this document, the following terms and definitions are used:

Hydraulic — indicates that the 'setting' process (chemical reaction that results in strength gain) is predominantly by the reaction with water.

Natural Hydraulic Lime (NHL) — a lime produced from a naturally occurring 'impure' limestone/ chalk. Typically the impurities are those of clay minerals and other sources of alumina and silica. (AKA: Eminently, Moderately, Feebly Hydraulic Lime).

Hydraulic Lime — a lime produced by the blending of calcium hydroxide, calcium silicates and calcium aluminates. This is commonly achieved by blending calcium lime (CL) and suitable pozzolanic materials.

Hydrated Lime — a lime produced from relatively pure limestone/chalk, composed predominantly of calcium hydroxide. The 'setting' process is mainly through carbonation, a reaction with carbon dioxide in the air and dissolved in rain water. (AKA: Calcium Lime (CL), Air Lime, Non-hydraulic lime, Building Lime, Fat Lime, Lean Lime).

Pozzolan — a Pozzolan or Pozzolanic Materials are reactive materials that when in the presence of soluble calcium hydroxide form hydrated compounds which act as binders. Often added to increase strength gain in both Hydrated, Hydraulic and Natural Hydraulic Lime mortars. In BS EN 459-1:2001 pozzolan additions to a lime are indicated by the letter Z following the lime designation e.g. NHL 3.5-Z.

Lime Mortar — a 'true' lime mortar is one where the binder is either a hydrated or hydraulic lime, (NHL or HL). Unfortunately it is commonly used to indicate that a volume of hydrated lime has been added to an Ordinary Portland Cement (OPC) based mortar. Typically between ½ and 1 part of hydrated lime is mixed with 1 part of OPC.

Both NHL and HL are now classified on the development of strength attained at 28 days, in the same way as cement-based materials. BS EN 459-1:2001 identifies 3 classifications of both NHL and HL.

Hydraulic Lime Classification	7 day strength MPa	28 day strength MPa
NHL 2, HL 2		≥2 to ≤7
NHL 3.5, HL 3.5		≥3.5 to ≤10
NHL 5, HL 5	≥2	≥5 to ≤15

Table 1 NHL and HL: Strength Classifications.
Source: BS EN 459-1:2001

NHLs (and HLs) fall between the strengths gained by carbonation (uptake of CO_2) of the hydrated limes (see box) which are typically <2 MPa, and those achieved by the hydration process of Ordinary Portland Cement (OPC), typically 32.5 MPa at 28 days. It should be noted, however, that NHLs and HLs will continue to gain strength beyond the 28 day reference point used in the Standard.

Where greater strength is required, the Standard permits the addition of a pozzolanic material, such as pulverised fuel ash, volcanic ash, ground granulated blast furnace slag and, traditionally, fired brick, to an NHL. In Europe, OPC is also commonly added. This material then becomes known as an NHL-Z and will achieve strengths greater than the corresponding NHL strength class.

Limestone

Natural hydraulic limes

There are a number of reasons why demand for NHL-based mortars has increased recently:

Environmental Issues NHL is seen as a more environmentally-friendly hydraulic binder. This is because the energy required to produce this material is significantly less than that for OPC and other cements. This is because the raw materials are calcined at much lower temperatures.

Technical Issues NHLs allow the masonry to 'breathe' by permitting the free movement of water vapour through the mortar, as well as the masonry unit. They attain strengths, which, though weaker than cement-based mortars, are acceptable for modern construction methods.

Structural Issues The weaker nature of the mortars made from NHLs allows for the accommodation of minor settlement and avoids the formation of mortar cracking. Any cracks formed tend to seal themselves by the process of autogenous healing where cracks are sealed by the deposition of calcium hydroxide, which then subsequently carbonates. Some architects prefer NHL and HL mortars, which preclude the need for expansion joints in long runs of brickwork. Irreversible moisture expansion of bricks set in OPC mortar results in a detachment of the brick and mortar (due to the strong/ brittle nature of OPC mortars). HL and NHL mortars are weak enough to plastically deform and allow for minor movement, and thus avoid the need for expansion joints every 15 m of brickwork.

Heritage Issues For the last 10–15 years, most heritage repair work has been based on the use of either hydrated lime or NHL-based mortars. This sector tends to avoid the use of incompatible, strong OPC-based mortars. Work by conservation bodies has shown the benefits of this approach, and currently the majority of this type of work will only specify NHL (rather than HL) if a hydraulic lime is required.

NHL is considerably more expensive than cement, because of small-scale production, and currently supplies only a small specialist market. However, the Building Limes Forum consider that there will be an increase in demand for all types of NHL in the future.

Supply

NHL was formerly produced on a relatively small scale but at many locations throughout the UK. Overall production was, therefore, substantial. However, in recent years production has been confined to one kiln at Tout Quarry near Charlton Adam in Somerset where production started in 1994 and continued until November 2004. Output was very small (<1000 t/y). A planning application to transfer production to another site in Somerset was turned down, following an appeal, in 2003. Currently, therefore, there is no indigenous supply of NHL in Britain and all demand is met by imports. However, consideration is being given to producing NHL at Melton Ross, near Brigg in North Lincolnshire using siliceous and argillaceous chalk as feedstock. Trial production has begun.

Trade

The UK market for NHL has, for many years, almost entirely been supplied by imports, mainly from western Europe. Recent trade in hydraulic lime is shown in Table 2. Provisional data for 2004 indicate that imports increased substantially in 2004. The figures may include some hydraulic lime other than NHL.

Economic importance

There is no current production of NHL in the UK. Should production restart the value of this output would be small. The main value would reside in having an indigenous supply for use in the specialised conservation market.

Consumption

NHLs currently supply a specialist market in the UK and consumption is very small and believed to be only in the range 10–14 000 t/y. All of this is now supplied by imports, which are increasing. By comparison UK consumption of OPC is about 12 Mt/y.

Structure of the industry

The only recent producer of NHL in Britain has been Hydraulic Lias Limes Ltd, which produced small quantities at Tout Quarry, near Charlton

	Tonnes					£ thousand				
	2000	2001	2002	2003	2004(p)	2000	2001	2002	2003	2004(p)
Imports										
Hydraulic lime:	1 549	1 267	12 663	14 629	24 154	332	149	1 348	1 706	3 678
of which from:										
France				9 741	17 542				1 256	2 967
Irish Republic				4 286	4 791				301	320
Exports										
Hydraulic lime	1 367	1 565	259	201	112	215	233	26	38	26
of which to:										

Table 2 UK trade in hydraulic lime, 2000–2004. Source: HM Customs & Excise.
Imports from the Irish republic are reported to originate in Italy
(p) Provisional

Adam in Somerset between 1994 and 2004. The company applied for planning permission to transfer production to Appledoor Quarry also in Somerset but permission was refused following a public inquiry. Consequently there is no current production.

Singelton Birch Ltd, a large independent lime producer based at Melton Ross, near Brigg in North Lincolnshire, is exploring in association with Hydraulic Lias Limes, the potential for producing NHL from chalk raw materials. Trial production is being carried out.

Resources

Resources of hydraulic limestone suitable for the manufacture of NHL are believed to be large. Recent production has been based on the Blue Lias Formation of Lower Jurassic age in Somerset but any argillaceous (clayey) limestone is likely to have potential. For example, impure parts of the Cretaceous Chalk have also been used comparatively recently. The Blue Lias Formation, which consists of thinly interbedded clayey limestone and calcareous mudstone or siltstone, crops our extensively from Dorset northwards into the Midlands. It also occurs in South Wales. The Blue Lias is currently worked for building stone and for cement manufacture.

Alternative resources of argillaceous limestone that have been worked in the past occur in parts of the Cretaceous Chalk (Grey Chalk in southern and eastern England and the Red, Ferriby and Welton chalks further north), and also within parts of the Carboniferous Limestone throughout the UK.

Reserves

There are no permitted reserves of hydraulic limestone specifically for the production of NHL. It is likely that existing permitted reserves, notably for the extraction of Lower Jurassic limestones for use in cement manufacture, as building stone or in the overburden to the extraction of other minerals (i.e. gypsum) and Cretaceous Chalk, have potential for use in the manufacture of NHL.

Relationship to environmental designations

Limestones, including chalk, give rise to some of England's most attractive scenery and consequently extensive parts of these resources are covered by national landscape designations. However, current proposals for chalk extraction and NHL manufacture would be from locations outside major landscape and nature-conservation designations.

Extraction and processing

Natural Hydraulic Limes are produced by calcining argillaceous or siliceous limestones at temperatures of around 1200°C. These temperatures are higher than those typically used for the production of quick lime (CaO), typically around 1000°C, but much lower than those used to produce cement (typically around 1400°C).

Most NHL manufacturers use vertical or shaft kilns, either as a batch (intermittent) or continuous process, though there are some examples worldwide that use rotary kilns (cement clinker type). Limestone is generally mixed with a pure anthracite coal (or metallurgical and/or petroleum coke) before being discharged into the kiln. Coal assists in obtaining an even temperature within the kiln and minimises the production of under-fired lime.

Once fired, the material is discharged and a controlled amount of water added to hydrate, or 'slake' the lime. This process results in the conversion of the lumps of lime into a powder. If this process is incomplete, additional grinding can be used to obtain the correct fineness for the lime. Most NHLs have particle sizes predominantly less than 10 microns.

During the firing process, calcium carbonate from the limestone, together with alumina and silica phases in clay and sand impurities, is converted into calcium aluminates, di-calcium silicate (belite) and calcium hydroxide. The lime may also contain unreacted and inert minerals from the raw material. The predominant calcium silicate is di-calcium silicate ('belite'), rather than tri-calcium silicate (alite) which is commonly found in OPC clinkers. When hydrated, belite gains strength much slower than alite, thus making the setting process more able to accommodate minor movement. At 28 days, belite attains approximately 10% of the strength (weight for weight) of alite, although similar strengths are achieved by 360 days.

The chemical composition of NHLs (influenced by the levels of impurities in the limestone from which they were made) directly affects the nature and physical properties of the NHL being produced. In general terms, limestones containing <12% reactive impurities will produce an NHL 2, 12–18% reactive impurities will produce an NHL 3.5 and 18–25% reactive impurities an NHL 5, although it should be noted that these compositions are approximate.

By-products

Currently there is no production of NHL in the UK, except on a trial basis. There are no by-products of the manufacture of NHL. Any future production of NHL, in the immediate future, is likely to be as an ancillary activity to the production of much larger quantities of other lime products.

Alternatives /recycling

The principal alternative to NHL-based mortars for construction purposes are those made using Hydraulic Lime (HL). HLs are produced by blending calcium lime (CL90) with a pozzolan (see box). In the UK, pozzolans used for this purpose are typically ground granulated blast furnace slag (GGBFS) or pulverised fuel ash (PFA), which are by-products of ironmaking and coal-fired power stations, respectively. Some pozzolans may introduce undesirable aesthetic properties and/or soluble salts. BS EN 459–1:2001 also allows the addition of OPC cement as a pozzolan. HLs made in this way are hybrids between non-hydraulic limes and cements.

Although HLs are generally not an acceptable substitute for NHLs in restoration, there is a market for HLs in the new building sector where these products are viewed as weak cements. Provided the correct strengths are attained at 28 days, developers, specifiers, architects and engineers may use this type of binder in mortars.

Practical considerations preclude the recycling of mortars made from NHL and HL. However, the use of NHL- and HL-based mortars can considerably improve the efficiency and practicality of recycling masonry units made from stone, block or brick. This is due to the lower strengths of mortars of this type, making them easier to remove from the masonry units and thus easier to recycle.

Natural hydraulic limes

Effects of economic instruments

Raw materials used in the production of lime-based products are not subject to the Aggregates Levy.

The Climate Change Levy was introduced in April 2001 as an environmental tax on the use of energy. Its purpose is to encourage the efficient use of energy in order to help meet UK targets for cutting greenhouse gas emissions. It applies to energy intensive sectors, including the cement and lime industries. In exchange for an 80% rebate from the Levy, the UK cement industry has agreed to reduce its primary energy consumption by 25.6% per tonne of cement produced by 2010 from a 1990 baseline figure. This target will be progressively met by a combination of replacing older plant, introducing alternative fuels and alternative materials, such as PFA and ground, granulated blastfurnace slag.

The production of NHL results in lower carbon dioxide emissions per unit of product than the manufacture of OPC. This is mainly due to the lower temperature at which calcination takes place. The 'greener' image of this material may become of increasing interest for new building work in the future.

Transport issues

Transport is not currently an issue because of the small quantities involved.

Planning issues

There are no planning policy references to the extraction and/ or processing of NHL raw materials in National policy, Regional or Local plans.

A planning application for what would have been the sole manufacturing site for NHL in the UK at Appledoor Quarry in Somerset was refused on appeal in 2003. The planning inspector recognised that indigenous production of NHL has undoubted advantages over imports in terms of overall sustainability. It was also stated that NHL represents a low energy alternative to Ordinary Portland Cement and that it has some advantageous characteristics, particularly in the restoration and conservation of historic buildings. However, in the case of Appledoor Quarry, none of these factors were so overriding that significant environmental impacts could be set aside. Impact of 24 hour working and noise/odour/dust on properties local to the site were cited as the main impacts.

The inquiry highlighted the dearth of knowledge on alternative sites in the Blue Lias (or other limestones) which might have less environmental impact. It also highlighted the lack of quantitative information on the future need for NHL. The combined effects of these factors will make planning difficult both strategically and in individual cases. MPAs will be able to cite the Appledoor Inspector's argument that the need for any particular site is not compelling, as no-one could be sure that no other suitable alternative sites exist that might have less environmental impact. This puts small businesses contemplating this market in a difficult position, as they lack the resources for a major review of alternatives that seems to be called for.

The current alternative proposal for the supply of NHL using chalk raw materials would make use of existing permitted reserves of chalk. In addition, it would utilise long established, and much larger, lime manufacturing facilities. The planning issues associated with this proposal are consequently much smaller than with a greenfeld site.' However, this does not preclude the possibility of planning applications for the small-scale production of NHL in other areas to produce regional types of NHL.

Further information

Mortars and Cements. L J Vicet, 1837. Reprinted 1997 by Donhead Publishing Ltd. ISBN 873394-26-8.

BS EN 459-1:2001 Building Limes: Part 1. Definitions, specifications and conformity criteria. Published by BSI. 2001.

Hydraulic Lime Mortar for Stone, Brick and Block Masonry. Donhead Publishing Ltd 2003. ISBN 1 873394 64 0.

Natural hydraulic limes

Building with lime, S Holmes and M Wingate. Published by ITDG. ISBN 85339-547-1. Reprinted and updated 2003.

The English Heritage Directory of Building Limes. Ed J M Teutonico. Donhead Publishing Ltd. 1997. ISBN 1 873394 21 7

Lime and Lime Mortars. A D Cowper 1998. Republished by Donhead Publishing Ltd (First Published in 1927 by Building Research Station).

www.buildinglimesforum.org.uk.

Authorship and Acknowledgments

This factsheet was produced by the British Geological Survey for the Office of the Deputy Prime as part of the research project 'ODPM-BGS Joint Minerals Programme.'

It was compiled by Andrew Smith (CERAM Research), David Highley and Andrew Bloodworth (British Geological Survey) and Richard Bate (Green Balance), with the assistance of Deborah Rayner (BGS).

The advice and assistance of the the industry, English Heritage and The Building Limes Forum is gratefully acknowledged.

Mineral Planning Factsheets for a range of other minerals produced in Britain are available for download from www.mineralsUK.com

Limestone