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Fuelling the Foundation Industries: Discovering the Hidden Value of Mineral Waste in the UK †

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Abstract: The Foundation Industries (FIs) (chemical, cement, ceramic, glass, metal, and paper sectors) are worth GBP 52 billion to the UK economy and produce 75% of its materials and 10% of its total CO_2 emissions. The UK extractive industry annually supplies millions of tonnes of mineral products used in FI manufacturing processes. It is estimated that mineral extraction results in upwards of 50 million tonnes of mineral waste every year. In 2021, the British Geological Survey embarked on a series of visits to UK mineral operations to improve the understanding of mineral waste production, composition, and its potential for use. This has enabled the sharing of data and information on poorly understood stocks and flows of waste materials between different industries and led to potential new applications for use of mineral wastes in novel polymer coatings and investment casting.

Keywords: mineral extraction; waste; Foundation Industries; mining; quarrying; statistics

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1. Introduction

The Foundation Industries (FIs) are the bedrock of industrial manufacturing in the UK. They include the chemical, cement, ceramic, glass, metal, and paper sectors. Cumulatively, these sectors are worth GBP 52 billion to the UK economy and produce 75% of its materials and 10% of its total CO_2 emissions [1]. The FIs are significant mineral consumers and use at least one or more of the products from the UK minerals industry (Table 1). Examples of use in the FI include gypsum in cement and ceramics [2]; kaolin in cement, ceramics, glass, and paper [3]; and silica sand in ceramics, chemicals, glass, and metals [4].

Waste is defined by the Mining Waste Directive as "any substance or object which the holder discards" [5]. In this paper, a broader definition of mineral waste is used which encompasses all material that is extracted by a mineral operation and remains unsold. The economic potential of this material is a key driver for research. Waste is an inevitable consequence of mineral production. The act of mineral extraction and processing involves selection, size reduction, and separation into products. The final desired mineral product leaves in its wake a trail of over- and inter-burden, scalpings, oversize, fines, tailings, slimes, and dust. Multiplied across the 2000 or so mining and quarrying operations in the UK, this adds up to the production of a large volume of mineral waste.

The UK generated 222.2 million tonnes of total waste in 2018; of this Figure, 62% (137.8 million tonnes) is Construction, Demolition and Excavation Waste (CDEW), including waste from mineral operations [6]. However, it is not possible to separate out the waste arising from mineral operations as it is aggregated with all other types of CDEW.

Due to a lack of publicly available data on mineral waste production, the only means of estimating the amount of mineral waste produced in the UK is to use waste to product ratios. This method has been used in the past in UK Government statistics for material flow accounting. For example, a waste to product ratio of 1:9 is used for construction aggregate. This is based on an estimate that 10% of the material extracted from a quarry ends up as waste of one form or another, i.e., 10 tonnes of material extracted from a quarry yields

1 tonne of waste and 9 tonnes of product. The mineral waste ratios used in this paper are largely derived from consultation with mineral operators in the UK as part of research projects carried out by the BGS and from the UK Minerals Forum [7]. The waste to product ratios are then applied to the mineral production data published by the British Geological Survey (BGS) in the UK Minerals Yearbook [8] to produce waste estimates.

As shown in Table 1, in 2021, it was estimated that 47.4 million tonnes of mineral waste were produced in the UK, based on 207.1 million tonnes of mineral production (excluding oil and gas). Currently, the largest volumes of mineral waste produced in the UK are those associated with the production of construction aggregate from hard rock quarries and sand and gravel operations. This was estimated to be around 21 million tonnes in 2021.

Table 1. Estimate of mineral waste production in the UK based on 2021 mineral production data and waste/product ratios.

Mineral Product	Mineral Waste Thousand Tonnes	Waste/Product Ratio	Mineral Production Thousand Tonnes
Coal, open-cast	14,400	15:1	960
Chalk, dolostone, igneous rock, limestone, sandstone, and slate	13,989	1:9	125,900
Sand and gravel	7175	1:9	64,577
Kaolin	6615	9:1	735
Polyhalite	1973	2.5:1	789
Clay and shale	1336	1:3	4008
Ball clay	1044	1.5:1	696
Silica sand	849	1:5	4245
Coal, deep-mined	31	1:3	94
Fluorspar	30	2:1	15
Talc	1	1:1	1
Barytes	1	1:21	27
Rock Salt	0	0:1	2688
Gypsum	0	0:1	2400
Total	47,444		207,135

The mineral waste estimates shown in Table 1 are a generalisation; however, in the absence of other data, they are the best available means of estimating UK mineral waste production. There are many instances where the amount of waste produced varies significantly from that derived from the waste/product ratios used. For example, the production of High Specification Aggregates (HSAs) from sandstone often results in a significant amount of waste being produced. In extreme cases, the waste generated to produce sandstone HSAs can be up to 50% of that extracted from the quarry. The production of gypsum from underground mining operations is close to zero. However, in surface gypsum quarrying operations, there can be a significant amount of waste produced. To resolve these variations, production data would be required for individual operations, including the amount of waste produced in each case. This data are either not available, due to commercial sensitivity, or not collected.

Most mineral waste produced does not leave the quarry or mine site where it was extracted. It is used for creating quarry haul roadways, screening bunds, backfilling of voids, and in site restoration works as part of the mineral planning permission for the operation. In this sense, this material is not considered as waste as it has a perfectly acceptable use. Minimal waste from quarrying operations is sent to landfills. In 2020/21, only 13,221 tonnes of waste were sent to landfill by members of the Mineral Products Association [9]. Mineral waste qualifies for the lower rate of UK Landfill Tax (currently GBP 3.25 per tonne) as it is largely 'inactive waste' that is non-hazardous, with low greenhouse emissions and low polluting potential [10]. The UK Aggregates Levy (currently GBP 2 per tonne) does not apply to mineral waste if it is not 'commercially exploited' and does not leave the site where it was extracted. The Aggregates Levy does not apply to processes creating any kind of flat stone, production of lime or cement, using shale for something other than construction, and extracting or separating certain industrial minerals from aggregates. The Aggregate Levy does not apply to mineral waste sent to landfills as it is subject to Landfill Tax [11].

2. Past BGS Mineral Waste Research

The introduction of the Landfill Tax in 1996, the Aggregates Levy in 2002, and the EU Mining Waste Directive in 2006 focused minds in the UK minerals industry on what constitutes mining waste and initiated many new attempts to reduce, reuse, or recycle mineral waste. A significant amount of research was carried out in the late 1990s and early 2000s to identify new uses for mineral waste, and some of it was carried out by the BGS.

In 1998, the BGS was part of the European Commission BriteEuRam programme project "REFILL: Development of novel processing for the production of low-cost by-product fillers as a replacement for high-cost primary fillers" (1998–2001), which involved the characterisation and evaluation of quarry waste in Europe for use as industrial minerals (in the UK, Ireland, and Greece). The BGS was responsible for the characterisation of quarry waste from selected aggregate quarrying operations across the UK. Quarry fines from quarrying operations (49 in the UK and 1 in Ireland) were characterised; these included a range of lithologies comprising diorite, dolerite, dolostone, granite, limestone, sand and gravel, sandstone, and trachyte. This remains one of the most comprehensive data sets published on the composition of quarry fines from active mineral operations in the UK [12,13].

In 1999, the BGS developed a research project known as 'Minerals for Waste' (DfID KaR R7416; 1999–2002), which was funded by the UK Government Department for International Development (DfID). This project aimed to improve the sustainability of mining communities by investigating the use of mineral waste as a source of construction and industrial minerals (based in Namibia and Costa Rica) [14].

In 2004, the BGS was involved with three Aggregates Levy Sustainability Fund (ALSF) research projects. 'Quarry Fines Minimisation' (MA/4/5/003) (2004–2007) investigated the potential to minimise the amount of quarry fines arising from the production of construction aggregate [15–17]. 'Waterless Fines Removal' (MA/4/5/002) (2004–2007) investigated the potential for the recovery of fines without the use of water [18]. 'Exploitation and Use of Quarry Fines' (MA/2/4/003) (2005–2007) investigated industrial applications for quarry fines [19]. In 2006, the BGS published a report on the nature of waste produced by active mineral workings in the UK [20], which was followed up by a report in 2010 on the nature of waste associated with closed mines in England and Wales [21].

3. Current BGS Mineral Waste Research

The current need for mineral waste research is driven by similar imperatives to those 25 years ago. In the 1990s, it was recognised that resources are finite, that the environment needed protection, and that global warming was a threat to humanity. In 2023, this translates into resource efficiency and circular economy, tightening regulations to control the impact of mineral operations and the drive towards industrial decarbonisation and net zero. Added to this is a concern regarding resource security and risk to supply, which has sharpened the focus on indigenous mineral resources amidst increasingly competitive global demands for raw materials. There has been no change in the apparent lack of information on the technical quality and production of mineral waste [22].

The BGS is currently part of the TransFIRe (Transforming the Foundation Industries Research and Innovation Hub) research project (2021–2024) which is funded by UK Research and Innovation (UKRI) as part of the Industrial Strategy Challenge Fund (ISCF)

Transforming Foundation Industries (TFI) challenge [1]. The aim of TransFIRe is to develop innovative technology to reduce energy and resource use within the foundation industries—which include the cement, glass, ceramic, paper, metal, and bulk chemical sectors. The project is looking at new ways to reduce waste and energy use and in a new research facility to accelerate the development of promising clean technologies.

As part of TransFIRe, the BGS is working to gain a better understanding of the composition and production of mineral waste in the UK. The aim of this ongoing project is to survey mining and quarrying operations that represent the full spectrum of minerals produced in the UK (as shown in Table 1). This will help refine the waste/product ratios used in the estimation of mineral waste production and provide more data on the composition of mineral waste for potential consumers, such as those in the Foundation Industries, to consider using in their manufacturing processes.

The explored mineral operations included ball clay, barytes, basalt, chalk, fluorspar, gypsum, kaolin, limestone, salt, sand and gravel, silica sand, and tungsten. Mineral waste samples collected include quartz- and lignite-rich ball clay, intrabasaltic laterite, carbonate-rich tailings from fluorspar processing, shale and sandstone from limestone quarrying, quartz- and mica-rich tailings from kaolin processing, tailings from sand and gravel processing, ultrafine quartz-rich tailings from silica sand processing, and tailings from tungsten processing. The initial characterisation of mineral waste has included analyses to determine its mineralogical (X-ray diffraction analysis), chemical (X-ray fluorescence analysis), and physical properties (particle-size analysis). There is initial interest in silica sand tailings for use as a mineral filler in research by Northumbria University on the use of waste PET (polyethylene terephthalate) and bio-derived components to produce novel alkyd-resin polymer coatings. Other potential applications include raw material for ceramic moulds used in the investment casting process. More mineral operations will be visited in the last year of the TransFIRe project, including those producing andesite, dolostone, granite, greywacke and sandstone HSA, limestone, sandstone, and slate.

4. Conclusions

Mineral waste is produced by most mining and quarrying operations in the UK. The amount produced in the UK, derived using mineral production data [8] and waste/product ratios, was estimated to be 47.4 million tonnes in 2021. Given the generalisation of the waste/product ratios used, the error margins on this estimate are likely to be in the region of +/− 10 million tonnes. Most of the waste produced by a mineral operation in the UK remains on the site where it was extracted and is factored into the development, and ultimate restoration, of the site. Since the introduction of the Landfill Tax in 1996 and Aggregates Levy in 2002, the UK minerals industry has been increasingly interested in research to find new applications for mineral waste. Despite a host of research projects being conducted over the recent 25 years, no large-volume applications have been developed beyond the more traditional uses as fill materials and other construction applications.

The systematic recording of mineral waste production and a better understanding of its properties is needed as a starting point to encourage its use. The data and information produced by the BGS as part of the TransFIRe research project is a good example of what is needed. This has already stimulated interest in the potential use of mineral waste in novel polymer coatings and in investment casting. Given the increasing drive towards resource efficiency, circular economy, industrial decarbonisation, and net zero, it is likely that there will be even greater regulations in the future, as well as the expectation from consumers, for an efficient extraction and use of mineral resources.

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Data Availability Statement: Data is contained within the article based on mineral production data available in a publicly accessible repository (Bide et al., 2023) [8].

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