The efficient use of GGBS in reducing global emissions

An appraisal of the global availability of ground granulated blast furnace slag

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"In the Low Carbon Concrete Routemap we identified that using ground granulated blast furnace slag (GGBS) as a supplementary cementitious material (SCM) to replace Portland cement is the current 'go-to' method for reducing the carbon intensity of concrete in the UK, that GGBS is a finite resource, and that use of GGBS as an SCM may result in a low carbon rating for a particular concrete but an overall increase in global greenhouse gas emissions (GHG) emissions. We identified a requirement for industry guidance on optimal use of GGBS to minimise global GHG emissions.

This guidance note provides further insight into the global availability and use of GGBS. It confirms that inefficient use of GGBS (to lower the embodied carbon of one project) can lead to an unintentional increase in global GHG emissions.

We encourage use of the simple three step process that the note describes to ensure appropriate use of GGBS. We strongly support the recommendation for a further technical study to investigate whether there should be a limit on the use of GGBS in concrete for the sole purpose of reducing carbon intensity."

The Low Carbon Concrete Group

Executive Summary

Ground granulated blast furnace slag (GGBS) is a co-product of the iron and steel industry, formed in the blast furnaces that create iron out of iron ore. It has been used as a supplementary cementitious material in concrete around the world since the end of the nineteenth century due to its technical properties (such as improving the concrete's durability).

However, as the concrete industry increasingly considers its role in the climate crisis and looks at ways of decarbonising its operations and products, the idea that GGBS can be used as a substitute for carbon intensive Portland cement clinker (referred to as 'clinker' in this paper) in concrete to reduce emissions has gained traction.

To help to determine whether this idea has merit, a group of experts drawn from across the concrete and cement industry, construction, academia and civil society undertook a literature review to better understand global production and utilisation of GGBS and clinker, and how this balance could change in the near-future.

The review indicates that global clinker production is currently 8x to 12x higher than global GGBS production and will remain at this order of magnitude to 2030 and beyond. It is found that around 90% of all iron slag is already processed into GGBS each year. No references were found to demonstrate significant usable GGBS stockpiles.

This review demonstrates that GGBS is a limited and constrained resource that is almost fully utilised globally. Any increase in its use in one location is highly likely to result in a reduction in use elsewhere, balancing each other out overall.

This paper concludes that whilst global supplies of GGBS must continue to be fully utilised to reduce overall clinker demand, any local increase in the amount of clinker substituted with imported GGBS is unlikely to decrease global emissions.

GGBS should continue to be used where required technically. Beyond this, it may still be specified where well-established supply chains exist, but it should not be used in high proportions in the hope of reducing global greenhouse gas emissions. It should also be noted that very high proportion mixes can lead to a need to increase total binder content if not managed through the project programme

Alternative options exist for reducing clinker usage and thus reducing global emissions, and designers should work with the supply chain to identify the best way to do this on each project. Concrete buyers and specifiers should recognise these issues and decide how best to align their ambitions to reduce emissions both on-site and globally.

Key messages

1. **GGBS is an excellent supplementary cementitious material that helps displace clinker demand globally.**
2. **However, GGBS is a limited and constrained resource that is almost fully utilised globally.**
3. **Therefore whilst global supplies must continue to be fully utilised, locally increasing GGBS use is unlikely to decrease global emissions.**
4. **Alternative options exist for reducing emissions when using concrete.**
5. **GGBS should still be used where required technically.**
6. **If GGBS is to be used beyond technical requirements, it should come from well-established supply chains, and be used in proportions cognisant of global constraints.**

Introduction

Ground granulated blast furnace slag (GGBS) is a co-product of the iron and steel industry obtained by water-cooling and grinding blast furnace slag. It is used as a supplementary cementitious material (SCM) in concrete due to its cementitious properties, which enhance the long-term strength and durability.

The technical benefits of including GGBS in concrete are now well understood and documented, but in recent years GGBS has also been a subject of discussion among concrete producers for its ability to partially replace Portland cement clinker (referred to as 'clinker' in this paper) and thus reduce the emissions of an individual concrete.

This briefing paper provides:

(1) An objective view of global GGBS availability, both present and future, through market and industry research.

(2) An appraisal of how global greenhouse gas (GHG) emissions can be affected by concrete mix designs.

(3) Recommendations towards the efficient use of GGBS, in reducing global GHG emissions.

This paper has been written in response to a need identified by both the Low Carbon Concrete Group routemap, and ConcreteZero, to better understand the availability of GGBS as an SCM. The paper has been prepared by volunteers, mostly from the UK. Whilst the data reviewed is global, it should be noted that the authors' most direct experience is based on the UK market.

This paper focusses on the issues around GGBS use and the embodied carbon of concrete. The authors wish to stress that embodied carbon is only one aspect of sustainability, and that sustainable concrete must account for other aspects such as resource depletion, social equity, biodiversity, etc.

The paper is relevant to all those who work with concrete that may contain GGBS, including novel technologies such as alkaline activated cementitious materials. Clients, designers, contractors and suppliers should use this paper to understand the three points listed to the left, to determine how they wish to use GGBS going forwards, in the light of the need to reduce global greenhouse gas emissions.

The paper uses terminology from BS EN 197-1:2001, *Cement – Composition, specifications and conformity criteria for common cements*, and equivalent standards as far as possible.[1]

1. Portland cement clinker: The dark grey nodular material produced by heating a mixture of limestone, clay, and other materials in a kiln at high temperature, which is the main component of Portland cement (CEM I).

Portland cement (CEM I): Portland cement is a type of hydraulic cement made by grinding Portland cement clinker, with a small amount of gypsum added as a setting regulator.

Cement (binder): A finely ground inorganic material or combination of materials that when mixed with water forms a paste that sets hard and can be used to bind aggregate together to form concrete or mortar.

Ternary cement: The type of cement (binder) that contains three main constituents: Portland cement clinker, and two other supplementary cementitious materials such as limestone fines, fly ash, GGBS, or pozzolana.

GGBS: Ground Granulated Blast furnace Slag, which is made by rapid cooling of slag melt of suitable composition, as obtained by smelting iron ore in a blast furnace, and containing at least two-thirds of glassy slag. Possesses hydraulic properties when suitably activated. The acronym GGBFS can also be used.

GBS: granulated blast furnace slag –GGBS before being ground. The acronym GBFS can also be used.

1. Global availability of GGBS

The research group conducted a review of existing literature to ascertain how much GGBS is typically produced each year, how much of this is used, and whether there is any spare. Here we summarise the findings from a selection of papers and reports.

1.1 Global production of GGBS

The following references give a range of global GGBS production levels from **330 to 407 Mt per year**.

Reference	GGBS global production (annual)	Year
Harder[2]	332 Mt	2021
CRU[3]	406.5 Mt	2021
	396 Mt	2022
US Geological Survey[4]	Estimated between 330 and 390 Mt (calculated as a % of iron production)	2022

1.2 Global production of clinker

Similarly, the following references give a range of global cement and clinker production levels. Where only cement was given, clinker has been calculated based on a clinker to cement ratio of 0.8 (as a conservative estimate led by the ratio shown by the US Geological Survey[4] reference). These numbers are shown in the table in *grey italics*.

The references give global clinker production levels to be in the range of **3340 to 3840 Mt per year**.

Reference	Cement global production	Clinker global production	Year
Cembureau[5]	4170 Mt	*3340 Mt*	2020
Van de Wegen[6]	4800 Mt	*3840 Mt*	2020
US Geological Survey[4]	4400 Mt	3700 Mt	2021
	4100 Mt	3800 Mt	2022

2. Harder J, Dec 2022, GBFS Focus 2030: Looking Beyond Europe, Global Cement Magazine
3. CRU Sustainability and Emissions Service, 2021
4. U.S. Geological Survey, 2023, Mineral commodity summaries 2023: U.S. Geological Survey, 210 p., https://pubs.usgs.gov/periodicals/mcs2023/mcs2023.pdf.
5. https://cembureau.eu/media/03cgodyp/2021-activity-report.pdf
6. Developments in main components of binders for concrete, Gert van der Wegen, SGS INTRON

1.3 Global GGBS utilisation

The following references all indicate that around 90% of all iron slag produced globally is already granulated by water quenching.

Reference	Statements on GGBS utilisation	Year
CRU[3]	Of total blast furnace slag produced, 90% was granulated.	2020 to 2022
Harder[2]	Granulation rate for blast furnace slag is currently 86.5%	2021
Nippon Slag Association[7]	Water-granulated slag makes up 86% of total slag production	2020 and 2021
China Iron and Steel Association[8]	The rate of blast furnace slag was 99.3% in 2022	2022

1.4 Future production predictions

The following references predict an increase in the production of both GGBS and the use of clinker. However, the ratio of GGBS production to clinker production is not predicted to change significantly by 2030.

It has been anecdotally suggested that there may be a reduction in clinker demand in East Asia (particularly in China) in the next decade, however it has not been possible to find any robust forecasts to confirm this.

Reference	GGBS production – predicted change this decade
Harder[2]	GGBS production predicted to increase to 381Mt by 2025 (+15%) and 416Mt by 2030 (+25%) Note this is partly due to a predicted increase in granulation rate from 86.5% (2021) to 93.4% (2030), and partly due to growth in BOF steelmaking across the world.

Reference	Clinker production - predicted change this decade
GCCA[9]	18% predicted increase in concrete use by 2030 when compared to 2020 levels. Clinker use could be expected to increase at the same rate without any intervention.

7. https://www.slg.jp/e/statistics/index.html
8. China Metallurgical News post on Weixin
9. https://gccassociation.org/concretefuture/wp-content/uploads/2022/10/GCCA-Concrete-Future-Roadmap-Document-AW-2022.pdf

1.5 Blast furnace slag stockpile data

The references to the right indicate that while there is some blast furnace slag stockpiled around the world, quantities are either small or unknown.

It has not been possible to quantify what proportion of stockpiled slag has been granulated versus air-cooled. Where stockpiled slag has been air-cooled, these stockpiles are unlikely to be suitable for use as an SCM, regardless of quantity.

In the event that slag has been quenched, ground, and stored as GGBS, we note that the material loses reactivity over time if it comes into contact with moisture. As such, any stored GGBS may not be suitable, nor have the required performance, for use in concrete.

Reference	Stockpile levels, location, usability
UK Department for Business, Energy and Industrial Strategy[10]	"It is known that there are rather small (less than 1 Mt in total) stockpiles of GBFS [GGBS], mainly at the Redcar plant."
US Geological Survey[4]	"[…] many sites have large slag stockpiles, which can allow for processing to continue for several years after the furnaces are closed or idled […]" The document does not provide any quantitative data or the method of cooling, therefore it is not known whether slag is suitable to replace cement.

10. https://assets.publishing.service.gov.uk/government/uploads/ system/uploads/attachment_data/file/660888/fly-ash-blast-furnace-slag-cement-manufacturing.pdf

1.6 Summary

Based on these references, we conclude that global clinker production is 8x to 12x higher than global GGBS production.

This ratio could fall slightly by 2030, if the future production predictions shown above are correct and a further ~10% of blast furnace slag were able to be converted into GGBS in the future, but would remain at the same order of magnitude (i.e., 7x to 10x).

We find no references demonstrating significant usable granulated blast furnace slag stockpiles. Moreover, even if stockpiles of blast furnace slags were to be identified, they may not be suitable, nor have the required performance, for use in concrete.

As such, we conclude that there is little opportunity for global GGBS production to increase significantly with respect to clinker use.

2. An approach to reducing global GHG emissions

2.1 Limited and abundant resources

Where a resource is globally limited, and is already highly utilised, then this resource offers limited opportunity to further decrease global emissions. To be clear: this is because the overall global level of resource use cannot increase. As such, any local increase in use is highly likely to result in a reduction in use elsewhere, balancing each other out overall.

Furthermore, if a limited resource is being used disproportionately as an SCM in regions where the production of clinker is lower-carbon than the global average, then the production of higher-carbon clinker must increase in the remaining regions, which is likely to increase overall global emissions.

Note that on the other hand, a local increase in the use of a resource that **does** have significant spare capacity within the global system (i.e., a resource which is globally abundant) is likely to decrease global emissions – as local usage can be increased without requiring a reduction in use elsewhere. However, we reiterate that this study does not indicate this being the case for GGBS.

2.2 GGBS as a limited resource

Section 1.6 highlights the limited capacity for significant increase in GGBS production in this decade, with around 90% of all iron slag already being converted into GGBS.

We therefore assume that the total amount of GGBS consumed globally will remain approximately constant in the short-term: GGBS being a limited resource.

This means that any local increase in the amount of clinker substituted with GGBS is unlikely to decrease global emissions. If overall global consumption of GGBS remains approximately constant, then increasing GGBS consumption in one region must reduce consumption elsewhere, and any effect on global GHG emissions is balanced out.

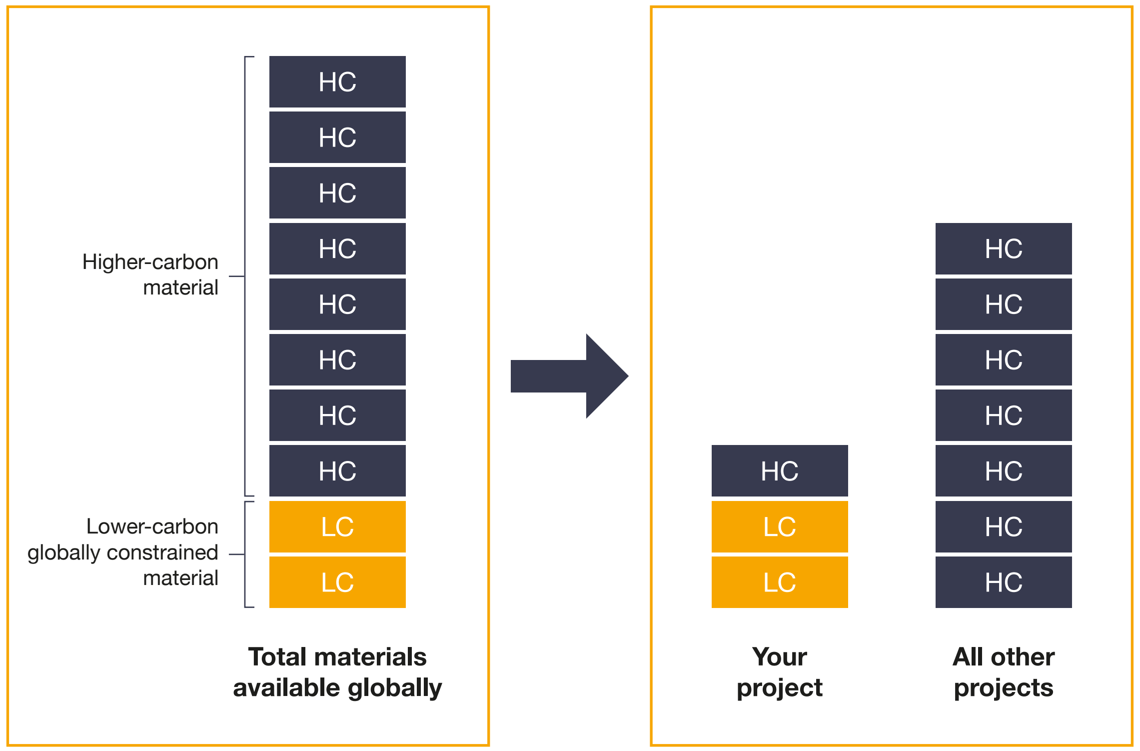

FIGURE 1:
Procuring higher than average proportions of a limited lower carbon supply has little to no overall benefit to global emissions.

2.3 Reducing global emissions

This does not mean that GGBS should cease to be used altogether. Such a move would increase global emissions as more clinker would need to be produced to compensate. While increasing GGBS use locally above current levels is likely to be ineffective in tackling global emissions, it is important that GGBS – where available – continues to be utilised.

GGBS should therefore continue to be specified and used where it is required technically, such as for durability or for temperature and crack control. It is recognised that, at present, there is some capacity for GGBS to be used and that many suppliers offer this within their concretes. If GGBS is to be used beyond technical requirements, it should come from well-established supply chains, and be used in proportions cognisant of the global constraints outlined in this paper.

It should also be noted that very high proportions of GGBS in a concrete can actually lead to increased total binder content and therefore increased clinker content to meet early-age strength requirements, thus negating any assumed reduction in GHG emissions. This should be tackled through appropriate coordination of concrete mix design and construction programme.

There are also many other ways to decrease emissions when using concrete without relying on GGBS. For example, other low carbon SCMs can be specified – and where these are proven and in local abundance, this will result in a decrease in global emissions when utilised as part of a low carbon mix design. Similarly, global emissions can be reduced through local clinker and concrete efficiency measures, as outlined in Section 3 of this paper.

2.4 Alkaline activated cementitious material (AACM) and geopolymer technologies

AACM and geopolymer concrete technologies are in development around the world. Many of these utilise GGBS in very high proportions. Research and Development into the next generation of replacement materials is key and GGBS is currently viewed as a necessary step in that development by AACM and geopolymer researchers.

The data presented in this paper, and the recommendations that follow, are the same regardless of whether GGBS is being considered for use in an AACM, a geopolymer, or a regular concrete.

3. Efficient use of GGBS in tackling global emissions

We recommend that three questions are asked early in the design process to optimise GGBS use, to be discussed with the contractor and supply chain to gain a better understanding of the project opportunities.

Question 1: Do we need GGBS for technical reasons?

GGBS brings enormous benefits to concrete being used in chloride-rich environments (such as marine structures, or infrastructure exposed to de-icing salts), and for temperature and crack control. Extensive guidance has been published on the use of GGBS, refer corresponding references throughout this document, and section 5, Further Resources. If there is a technical reason to specify GGBS on your project, then it should be used accordingly.

Note that there are other SCMs that can have similar technical benefits to GGBS, such as fly ash and other pozzolans. These should also be considered for use where technically feasible and where well-established supply chains exist.

Note also that it is unknown what overall proportion of concrete has such technical requirements. It is expected that this is less than the total amount of SCMs available, as in recent decades some clinker has been substituted for SCMs even when not specified in the concrete mix design.

Question 2: Is there a well-established GGBS supply chain for our project?

GGBS is stocked by many ready mixed concrete plants and precast manufacturers. Both the precast and ready-mix industry have the ability to vary the GGBS proportion to optimise the technical properties of the concrete, depending upon the requirements for any structure and the specification constraints.

If GGBS is being used beyond technical requirements, it should come from well-established supply chains, and be used in proportions cognisant of the global constraints set out in this paper. You should work with the local supply chain to agree a GGBS proportion in the context of these constraints.

Question 3: How else can we reduce concrete emissions?[11]

If neither question 1 nor 2 are answered with a "yes", then GGBS should not be used in high proportions just in the hope of reducing global greenhouse gas emissions.

If other, more abundant, clinker substitutes are available locally then they should be investigated for suitability in your mix design. The British Standard for concrete, BS 8500:2015+A2:2019, *Concrete - Complementary British Standard to BS EN 206*, has been revised (publication due late 2023) and this update will considerably increase the range of lower carbon concretes permitted by allowing new ternary cements to be specified, providing a route for more optimised use of GGBS within concrete. Other alternatives such as calcined clays are likely to offer more promise still in the near future.

Clinker efficiency measures will reduce total global clinker usage and thus reduce global emissions. Such measures include (but are not limited to) setting maximum clinker limits, better aggregate grading, more relaxed requirements for early strength gain, use of admixtures or performance enhancers.

Clinker efficiency measures should not be specified by the designers, but instead should be encouraged through specifications which limit carbon but allow flexibility in how the supplier meets them. This could include setting upper limits for the carbon emissions of the concrete – noting that very tight limits may currently be difficult to meet without adding high proportions of GGBS to the concrete.

Concrete quantity reductions should always be considered regardless of the concrete material specification. Structurally efficient concepts, arrangements and design all reduce the amount of concrete (and thus clinker) used, reducing global emissions.

11. https://www.ice.org.uk/media/200i0yqd/2022-04-26-low-carbon-concrete-routemap-final_rev.pdf

4. Conclusions

This paper concludes that any local increase in the amount of clinker substituted with GGBS is unlikely to decrease global GHG emissions.

GGBS should continue to be used where required technically. Whilst global supplies of GGBS must continue to be fully utilised to reduce overall clinker demand, any local increase in the amount of clinker substituted with imported GGBS is unlikely to decrease global emissions. As such, if GGBS is to be used beyond technical requirements, it should come from well-established supply chains, and be used in proportions cognisant of global constraints - it should not be specified in high proportions in an attempt to reduce global GHG emissions.

It should also be noted that very high proportions of GGBS in a concrete can actually lead to increased total binder content and therefore increased clinker content to meet early-age strength requirements, thus negating any assumed reduction in GHG emissions.

Alternative options exist for reducing clinker usage and thus reducing global emissions, and designers should work with the supply chain to identify the best way to do this on each project.

This aligns with the philosophy behind the updated PAS 2080:2023, Carbon management in buildings and infrastructure, which calls for thinking at a systems level, not just an asset level, and highlights the need to collaborate along the whole supply chain to reduce GHG emissions.

Given that the information provided in this paper points to global constraints in GGBS availability, we suggest that the relevant organisations conduct a technical study to investigate whether there should be a limit on the use of GGBS in concrete for the sole purpose of reducing carbon intensity, and how this could be practically implemented.

The information in this paper also highlights the disconnect between accepted life-cycle assessment methodologies (which focus on emissions within a project's boundary) and the issues presented by the use of globally limited resources, which should be considered further by the relevant standards committees.

This paper highlights that whilst GGBS is an excellent material and has helped displace clinker production historically, and should continue to be used, it cannot further reduce global emissions. Therefore an urgent acceleration in the development and scaling of other technologies is necessary to meet GHG reduction goals and the authors urge the industry to support new approaches and technologies wherever possible.

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