CONCRETE

Climate Friendly Purchasing Toolkit

WEST COAST CLIMATE & MATERIALS MANAGEMENT FORUM

Introduction

The production of concrete is among the most greenhouse gas intensive building materials, comprising up to 5% of global CO_2 emissions.[1] State and local governments have found that purchasing concrete contributes significantly to their GHG inventories. In fact, a study of 86 different public GHG inventories found that the purchase of concrete can comprise between 10 and 15 percent of all emissions (Good Company Meta Analysis, 2015). Since concrete is an essential material for both our transportation and building infrastructure, reducing the environmental impacts of concrete is of paramount importance. Fortunately, there are numerous ways to reduce the GHG impact of concrete mixes. Many of the methods which are discussed in this paper are not only well known by the concrete industry, but in some cases, are also cost competitive.

Greenhouse Gas Impacts of Concrete

Sources of Greenhouse Gas (GHG) emissions from concrete production include:

- The processing of limestone into cement which requires significant energy inputs and creates a chemical reaction that emits carbon dioxide[i]
- Quarrying, hauling, crushing, and screening of aggregates
- Handling, storing, mixing, and method of preparation of materials

Concrete is a composite material made from a mix of roughly 41% rough aggregate (such as gravel or crushed stone), 26% fine aggregate (such as sand), 16% water, 11% cement, and 6% air[ii] by volume. Cement is the binder in concrete that fills the cracks between the aggregate, hardens, and holds it in place.

Portland cement is the standard cement used to make concrete. Production of Portland cement is energy and GHG-intensive because it requires heating crushed calcium carbonate (limestone) to temperatures near 2,700°F in a kiln. This intense heat creates a chemical reaction that converts the calcium carbonate into calcium oxide (lime), which is used in the cement production. This process also releases carbon dioxide as a waste product, which increases the carbon intensity of cement production above and beyond the emissions from energy use in the kiln. The cement portion of concrete typically contributes to over 80% of the carbon footprints of concrete mixes (Figure 1).

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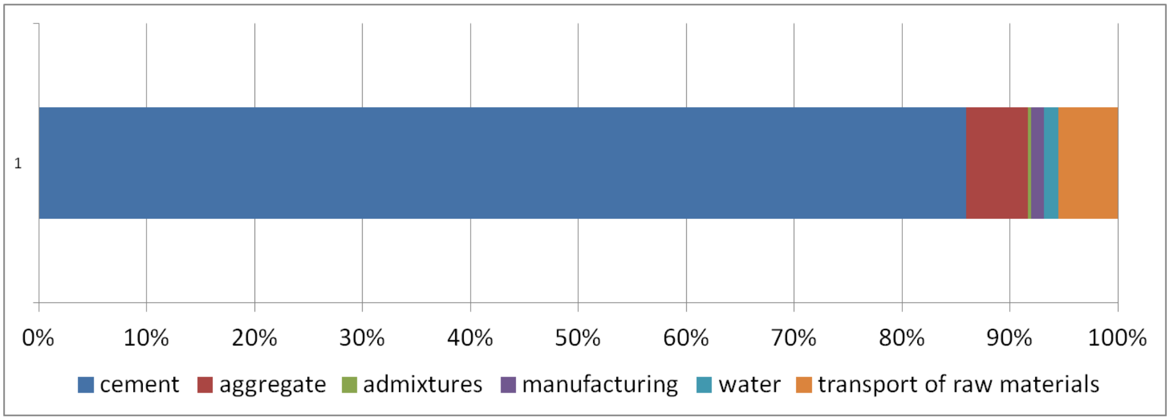
[1] Studies are referenced on this page https://en.wikipedia.org/wiki/Environmental_impact_of_concrete

Figure 1. Greenhouse Gas emission from a typical concrete mix – contribution analysis (4000psi mix, CSI tool, 2016)

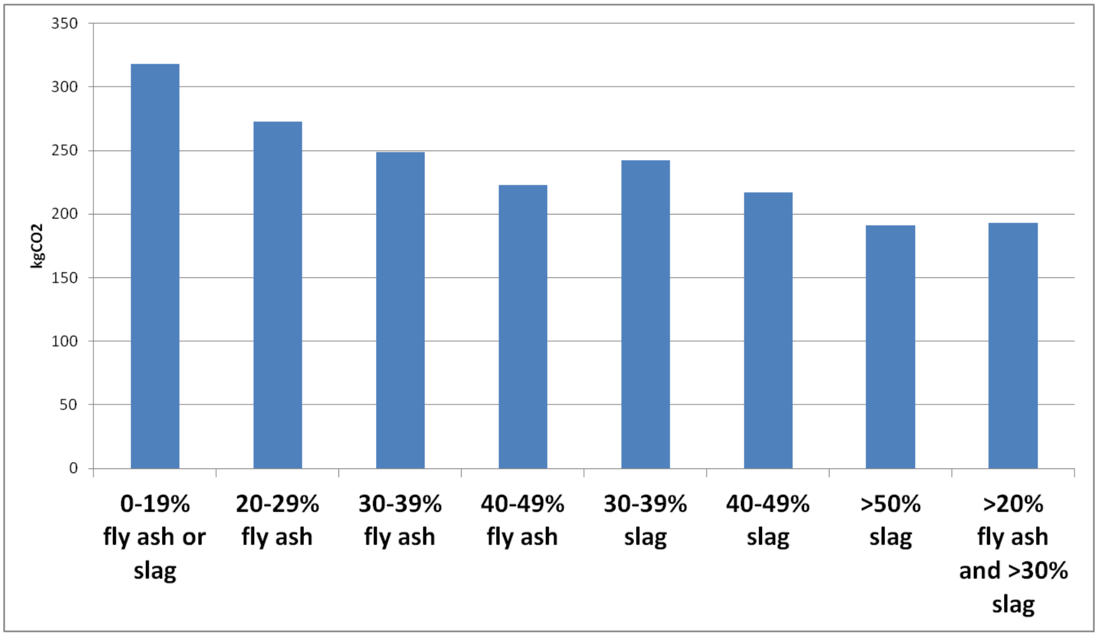


Opportunities to reduce the GHG impacts of Concrete

Given the high contribution cement has to the carbon footprint of concrete, the most effective means to reduce the GHG emissions from concrete is to simply reduce the cement content of the mix as much as possible. There are several materials that can act as partial substitutes to Portland cement, which can lead to GHG and cost reductions. The material substitution measures discussed here include the supplementary cementitious materials (SCM) called fly ash and granulated blast furnace slag (slag). Both of these materials can act as substitutions for Portland cement and are already well known in the marketplace. Substitution rates for these materials can range as high as 50-70%. In addition, using recycled concrete as a substitute for virgin aggregate is also considered in this section as a GHG reduction measure, although the GHG savings are considerably less than cement substitution. The reductions achieved using SCM can be substantial. For example, a 50% slag substitution will result in a 40% reduction of GHG impact of a standard 4000 psi mix. Figure 2 below shows the GHG reductions that can be achieved with varying levels of cement substitution.

Additional mixtures and substitutions to Portland cement are constantly being evaluated and added. Products such as glass, clays, natural volcanic ash, and other substitutes are entering the market and may be suitable alternatives to the strategies described in this section. Please refer to the section on Emerging Methods to Reduce the Carbon Content of Concrete below for more details.

Figure 2. Greenhouse Gas emissions from different concrete mixes - NRMCA national averages for 4000psi mixes



Purchasing Strategies to Reduce GHG impacts of Concrete

The most effective purchasing strategy for reducing the GHG impact of concrete is consuming less concrete. This document, however, will assume that the government purchaser using this guidance has already reduced their demand for concrete to the greatest extent possible and is now ready to purchase concrete. The following strategies can be employed to reduce the GHG impacts of concrete:

1. Request or require Environmental Product Declarations (EPDs)
2. Mandate minimum SCM use
3. Raise allowable SCM use
4. Provide financial incentives for SCM use or cement reduction
5. Request or require recycled aggregate for concrete mixes

Environmental Product Declarations (EPD)

EPDs are standardized ways of reporting the life-cycle environmental impacts of products. EPDs are like a "nutrition label" for products that report a selection of environmental impacts. This is similar to the nutrition labels on food, which report the measured nutrition facts for the food product. EPDs are third party verified and need to follow ISO 14025 guidance and procedures. Visit the National Ready Mix Concrete Association's (NRMCA) EPD website to view existing concrete EPDs (http://www.nrmca.org/sustainability/EPDProgram/Index.asp).

Figure 3. EPD "nutrition label" for concrete mixes

EPD "Nutrition" Label

Your Building Product

Amount per Unit

LCA IMACT MEASURES	TOTAL
Primary Energy (MJ)	12.4
Global Warming Potential (kg CO^2 eq)	0.96
Ozone Depletion (kg CFC^- 11 eq)	1.80E-08
Acidification Potential (mol H^+ eq)	0.93
Eutrophication Potential (kg N^- eq)	6.43E-04
Photo-Oxidant Creation Potential (kg 03 eq)	0.121

Your Product's Ingredients: Listed Here

Ready mix concrete EPDs all follow the same product category rules (PCR) so they can be comparable to one another. Product category rules are the accounting and reporting rules for EPDs. There are many efforts underway, especially in the building products realm, to ensure increased comparability of EPDs in the future. Nevertheless, governments should be cautioned about selecting a concrete producer solely on the basis of comparing their EPD to another company. Instead, ***a good interim step would be to reward companies that have EPDs during the bidding process with extra points***. That said, once a specific concrete producer is selected, the EPDs produced for mixes from an individual plant are very comparable to one another. This is because EPDs from the same concrete plant are all using the same background data to produce their EPDs. Thus, it's very reasonable to compare a standard mix design to a low carbon mix design from the same plant and have high confidence in the carbon reductions documented in the EPDs.

The green building market is starting to demand EPDs across the spectrum of building products. The US Green Building Council's LEED building rating system is the most widely used green building rating system for commercial buildings in North America. Version 4 of the LEED standard, which becomes mandatory for projects registering for certification after October 2016, is now rewarding points to products with EPDs and even more points to products that can show how their EPD has lower impacts compared to the industry average EPD for that product category. The result of this dramatic change in the LEED rating system is that many building product manufacturers are aggressively pursuing EPDs for their products. ***As government purchasers, asking for EPDs will not only signal the market that the impacts of producing building materials is important but will also allow purchasers to make measurable and substantial reductions in the carbon impacts of their purchases.*** Besides the quantified disclosure benefits for the purchaser, the EPD will also serve as a baseline for improvement for the producer of that product.

Another strategy related to EPDs is to request or require Environmental Product Declarations (EPDs) that show a % reduction below the National Ready Mix Concrete Association's (NRMCA) regional benchmarks. NRMCA is the national industry association for ready mix concrete producers. As a service to their members, NRMCA produced a national average EPD by surveying their members about the impacts of the production practices. This proactive strategy allows individual concrete producers to compare their plant specific EPDs to the regional or national averages for various mix strengths. Since NRMCA reports the average, one would expect half the producers in a region to be above the average and half to be below. Therefore, to encourage the selection of concrete mixes that perform better than the regional averages, government purchasers could request or require concrete bids to show a percent improvement below the regional averages for a given material class. For example, a government could request that EPDs submitted for a project show a 20% reduction of carbon impacts compared to the regional benchmarks. The big advantage of this approach is that it is performance based rather than prescriptive specifications. Performance based specifications allow for the most flexibility and creativity of the contractor to meet those specifications compared to the minimum and maximum SCM approaches described below.

NRMCA's industry average EPD can be found here:
http://www.nrmca.org/sustainability/EPDProgram/Downloads/NRMCA%20EPD%2012.07.2014.pdf

NRMCA's regional benchmark mixes can be found here:
http://www.nrmca.org/sustainability/EPDProgram/Downloads/NRMCA_Benchmark_Report_-_October_14_2014_web.pdf

Mandate minimum SCM use

Some infrastructure or building projects specify SCM minimums to reduce the carbon impacts of the mix. Examples include the following:

- Seattle Department of Transportation (SDOT) specifying that all sidewalks be constructed with a minimum of 25% SCM (Tracy, 2014 'add citation").
- California's High Speed Rail project also specifies minimum SCM for specific applications (cite http://www.hsr.ca.gov/docs/programs/construction/RFP_B4-PtC1_StandrdSpecification.pdf).

Minimum SCM specifications opens up a potential perception that the owner is starting to specify means and methods. With that comes a potential liability if mix designs meeting a target do not perform as expected (Sound Transit, December 2014). Although the risk of liability seems quite low, it is still a valid consideration when writing specifications. Another downside of minimum SCM specifications is that the carbon savings are not actually quantified. As expected, with higher the SCM percentages, the carbon impact of the mix is reduced. However, without quantifying business as usual compared to the low carbon mixes, governments may have a difficult time tracking the carbon savings that result from their purchases. In an era of increasingly important Climate Action Plans, quantifying carbon savings is an important factor.

Raise allowable maximum SCM use

Some governments create maximum SCM limits for various uses of concrete through their construction specifications. This can be a limiting factor when trying to create lower carbon mixes, sometimes called "lean" mixes, which have higher SCM percentages. Use of fly ash and slag are often capped at percentages that are lower that what the literature suggests is feasible, and also in some cases at percentages that are lower than caps put in place by the state agencies, as is the case shown in Table 1 below for the Seattle Department of Transportation (SDOT) and the Washington State Department of Transportation (WSDOT) (Tracy, 2014; Sound Transit, 2014, A.6). Even with these lower-than-necessary limits, most projects are replacing cement at well below the allowable maximum. The table below shows the results of a survey of over 15 different SDOT and WSDOT projects. As the Table 1 below makes clear, actual cement replacements are in most cases not reaching allowable maximums.

Table 1. Allowed versus Actual Replacement in WSDOT and SDOT mixes (Sound Transit, Dec 2014)

Application	Allowed Max. Fly Ash by either WSDOT or SDOT	Actual Max. Fly Ash in WSDOT or SDOT Mixes	Allowed Max. Slag by either WSDOT or SDOT	Actual Max. Slag in Peer Agency Mixes
General Purpose	35%	25%	50%	35%
Roadway Concrete	25%	25%	25%	25%
Bridge Decks	20%	16.7%	30%	0%
Elevated Approach	20%	16.7%	30%	0%
Temp. Guide Walls	Not Specified	0%	Not Specified	50%
Underwater	35%	0%	50%	0%
Pilings / Drilled Shafts	35%	25%	50%	50%

A report prepared for Sound Transit Authority identified 4 primary reasons that the actual SCM percentages achieved in Table 1 fall below the allowable maximums:

1. Concern around schedule delays due to the longer set times for high SCM concrete
2. A lack of compelling financial incentives that would offset the negative impact to the schedule
3. Lack of priority for public agencies and lack of encouragement for contractors to achieve the max allowances already in specifications
4. Lack of minimum SCM allows mixes to be in compliance w/o any SCM content. When minimums do exist, however, there is little incentive to ever exceed the minimum which stifles further advancement.

Provide financial incentives for SCM use or cement reduction

Overall, the use of compelling incentives can leave the mix design to the concrete supplier and contractor while still motivating project teams to propose mix designs that reduce cement. Government purchasers should consider meaningful incentives in markets that have less familiarity with SCM or markets that are meeting bare minimum SCM targets.

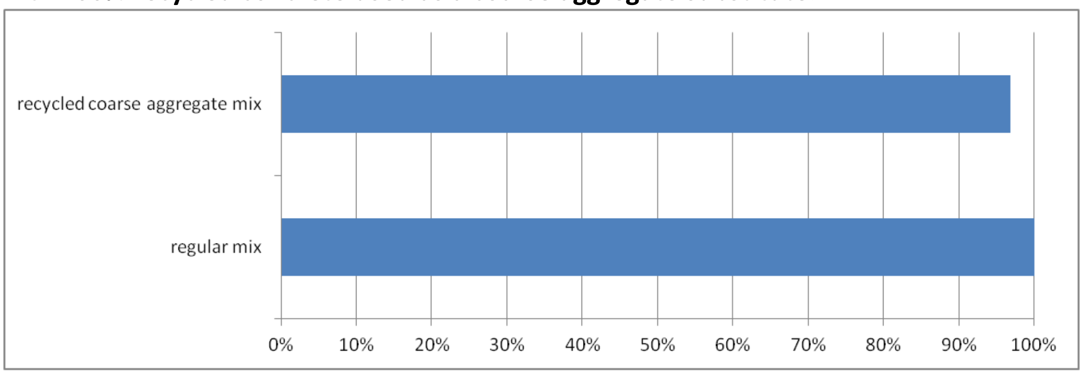
The Seattle Department of Transportation used to incentivize the reduction of cement content per cubic yard of concrete in road pavement through 2012 (Tracy, 2014; Sound Transit, 2014). They did this by setting cement maximums per class of material, then calculating a per pound incentive for each pound reduced in the mix below the maximum cement content. Overall, SDOT staff report that while the program did achieve GHG savings, the incentives were small compared to the total value of the construction contract. While the incentive was a factor to move toward lower cement mixes, it was likely not the prime motivation (Sound Transit, Dec 2014).

Request or require recycled aggregate for concrete mixes

The GHG emissions associated with virgin aggregate (rocks) are due to a combination of combustion emissions from transportation and material extraction. If using recycled aggregate, which is old concrete crushed to size, GHG emissions are reduced due to the avoidance of mining, crushing, and transporting virgin aggregate. Figure 4 below shows the GHG savings of using 100% recycled aggregate in a typical concrete mix. One can see that the GHG savings are real but they plateau at about a 3%

reduction. Additionally, current ASTM limits on structural concrete limit recycled coarse aggregate to 10%. While project specific testing can permit larger uses of recycled aggregate, using 100% recycled coarse aggregate would be very rare. Thus, the carbon reduction benefits of this strategy are likely overestimated. The use of recycled aggregate, however, has benefits beyond carbon reductions. Most notably, recycled aggregate conserves a non-renewable resource that is mined from land and waterways and can have environmental impacts far beyond carbon impacts. Therefore, while recycled aggregate should not necessarily be a primary strategy for reducing the carbon content of concrete mixes, it should remain a component of public purchasing when appropriate. Additionally, in remote areas, the transportation of aggregate can be a large environmental and financial cost, which could drive the use of recycled aggregate even further.

Figure 4. Comparison of Greenhouse Gas emissions from a regular concrete mix versus one made with 100% recycled concrete used as a coarse aggregate substitute.



Considerations for Implementing Purchasing Strategies

How is concrete purchased

State and local governments purchase concrete for constructing buildings or transportation infrastructure such as roads, bridges, and sidewalks. For most buildings, governments are not purchasing the concrete directly. Instead, they hire an architect and structural engineer to design the building and a general contractor to construct the building. The general contractor then subcontracts out to a concrete producer to supply the mix design specified by the structural engineer. The labor to set and finish the concrete is not typically associated with the concrete supplier either.

Purchasing concrete for transportation infrastructure is much different than building construction. In these cases, governments directly hire a concrete producer to supply the concrete. Project mix designs are often driven by local or state construction specifications. Generally, specifications have become less prescriptive over time and allow for more flexibility in mix design.

Who needs to be involved

For building construction, the desire to obtain a low carbon concrete mix should be communicated as early as possible. It's important that the architect and structural engineer be aware of the goal for low carbon concrete mixes during the design phase. The general contractor and the concrete producer should also be involved as early as possible. Ultimately, it's up to the structural engineer to provide concrete mix design specifications to the general contractor that meet the project's structural requirements. Specifications may include things like slump, air content, yield volume, water cement ratio, strength (at various time intervals), shrinkage, and set times. The general contractor controls the construction schedule and will hire a concrete producer that can deliver the desired mix designs. Early involvement of the concrete producer is also critical. Trial batches and past experience with high SCM mixes will help the producer inform the project schedule. The biggest challenge with low carbon concrete that has high SCM content are slow set times and low early strength. The contractor may need to leave the forms on longer and/or wait longer to reach the strength targets for that portion of the building.

Low early strength is the biggest issue that the general contractor needs to be aware of. Generally speaking, any concrete mix with SCM content above 30% may have low early strength. For example, a wall with 30% slag content may meet its 7 day strength target but a mix with 60% slag may take 14 days to meet the same early strength target. Overall, since the project schedule is affected by mix designs, the architect, engineer, general contractor, and the concrete producer should be involved as early as possible.

Where in procurement is intervention needed

In building construction, intervention is needed from the onset of hiring a design and structural engineering team. In fact, it's prudent to ask the structural engineer before hiring them what their experience is with concrete mixes that have high SCM content. Are they comfortable specifying them? Have they done it before? What's the highest SCM content they've specified in the past (anything over 40% SCM is fairly high in today's market)?

The general contractor is a critical piece of the procurement process too. When project goals for low carbon concrete are communicated early with the general contractor, they can put specific requirements in their subcontract with the concrete producer that outlines their expectations. The exact nature of the language will vary depending on which purchasing strategy is selected. Cement maximums, SCM minimums, and EPDs are all purchasing strategies that can work their way into contract language.

Specific info needed to change purchasing behavior

Using SCM in concrete is not a new concept for concrete producers. So, at the most basic level, the organization purchasing concrete simply needs to ask for a low carbon concrete mix that has high SCM percentage. As highlighted in "Purchasing Strategies" section above, there are a variety of strategies to procure a low carbon mix. The first step is choosing the strategy that works for your organization.

The role of construction specifications

Most public agencies have construction specifications that dictate the requirements for public works projects. There is value in specifications to clearly communicate project requirements and have consistency of quality among public works projects. However, in some cases, construction specifications lag behind what is technically feasible and may limit an agency's ability to procure low carbon concrete mixes. Short of changing the public specifications, most specifications will allow project by project variations if the mix designs are put through trial batches and proven to meet the strength and durability requirements of the project. Public agencies that are early adopters of low carbon concrete purchasing may have to pursue more trial batches and testing to demonstrate that the mix is appropriate.

Supplementary Cementitious Material (SCM) Overview

Fly Ash benefits and concerns

Fly Ash is a waste by-product from the combustion of coal. It is a very fine powder composed predominantly of silica, and is generally a light tan color. When combined with water, it produces a cementations mix that can be used as a substitute for a portion of the quantity of Portland cement in a blended concrete mix, generally 0 – 30%. However, the fly ash must meet strict standards, including standards on the fineness of the grain sizes, and that the composition is >20% lime.[iii] These standards are typically represented by Class C fly ash. Figure 5 provides a summary of the benefits and concerns associated with the use of Fly Ash.

Figure 5: Summary of Fly Ash benefits and concerns.

Benefits	Concerns
• **Stronger, denser, and more durable**[iv] • **Less permeable to corroding water**[xiii] • **Protects steel better than Portland cement**[xiii] • **Reduced risk of micro cracking**[xiii] • **Increased workability**[v] • **Reduced water usage**[xiii] • **Strength increased over time**[xiii] • **Produces white architectural concrete**[xiii]	• **Contains several chemicals that raise concerns about toxicity**[vi],[vii] • **Longer set time could delay construction times and reduce early strength** • **Transportation of fly ash can be cost prohibitive**[viii]

Performance Impacts

The use of fly ash can impact performance in ways that are different from the use of traditional Portland Cement. The use of high volume fly ash creates a stronger, denser, and more durable concrete. Fly ash concrete is also less permeable to water, particularly seawater and sulfates, making it ideal for use in those conditions. Concrete with fly ash is at less risk of micro cracking due to less heat created during hydration, and also does a better job at protecting reinforced steel. Due to the fine, round particles in fly ash, it is less likely to clump together during hydration, leading to greater workability, and because of its small particle size, it fills voids that otherwise would be filled with water in a traditional mix, leading to a lower water/cement ratio. Fly ash also produces a concrete that is white in color which reflects heat and reduces the urban “heat island” effect.

However, there are also concerns associated with the use of fly ash. Fly ash concrete takes longer to set into the glue that holds the concrete together than traditional Portland cement. The longer set times reduces the early strength of concrete with fly ash compared to Portland cement. Longer set times have the potential to delay construction schedules and are regarded as one of the main obstacles to using more fly ash. It’s difficult to estimate the exact difference in set times since there are many other factors that affect the set time such as air temperature, water temperature, sub-grade temperature (if applicable), admixtures, and cement type.

Cost

Fly ash has the potential to reduce the costs of concrete mixes. A report for Sound Transit Authority in 2014 interviewed a number of concrete suppliers in the Pacific Northwest and found that the cost of using SCM will range from a 8% cost savings to a 3.5% cost premium. In most cases, using SCM reduces initial costs but like any commodity, the cost of these materials changes over time. Concrete producers along the west coast procure their fly ash from a number of different sources, making transportation costs among the largest price variables. (Sound Transit, Dec 2014).

Availability

Fly ash is a byproduct of coal combustion. Major coal plants and sources of fly ash in Washington and Oregon will be shutting down by 2025, possibly constraining the local supply of fly ash. Other sources of fly ash mainly come from Canada and the Eastern United States. Although there is not expected to be a major shortage of fly ash, there may be an increase in price due to the longer transport distances required to obtain the fly ash. Fly ash is, however, subject to some degree of seasonal availability pressures based on hydropower production in certain regions. Specifically, if power plants are able to rely on more hydroelectricity, then they'll burn less coal to satisfy baseline power demands. Additionally, there is increasing pressure on coal fired power plants to switch to natural gas fired plants to cover their base load as the price of natural gas decreases.

Slag benefits and concerns

Granulated Blast Furnace Slag, also known as "slag," is a byproduct of iron a steel manufacturing that can typically replace 20-80% of Portland cement in concrete, depending on the application.[ix] Slag is a glassy, grainy material that, once ground into a fine powder, will react with water to produce a cementations mix.

Figure 6: Summary of granulated blast furnace slag benefits and concerns.

Benefits	Concerns
• Greater workability[x] **• Reduced risk of micro cracking**[x] **• Reduction of energy and GHGs**[xi, xii] **• Produces white architectural concrete**[xi] **• Creates a higher quality concrete that is stronger, denser, and more durable**[xiii]	**• Longer set time could delay construction times and reduce early strength**[x] **• Increased risk of salt scaling**[x] **• Human health and safety concerns**[xiv]

Performance Impacts

The use of slag can impact operations in ways different from the use of traditional Portland cement. Concrete containing slag has longer set times and therefore greater workability than concrete containing only Portland cement, which helps particularly during hot weather[x]. It also has a lower heat of hydration compared to traditional Portland cement, thus reducing the risk of micro cracking[x]. Slag produces a lighter colored concrete, which some might find more aesthetically pleasing, but can also reflect more light and reduced trapped heat[xi]. Slag concrete has a higher strength compared with straight Portland cement[xiii]. This is because the mixture is denser and contains more strength-enhancing calcium silicate hydrates. Concrete with slag is preferable when specific safety and strength standards need to be met.

However, there are some operational impacts of using slag that raise concerns. Slag concrete has a longer set time, and thus takes longer to develop initial strength[x]. Concrete with a high amount of slag is more likely to experience salt scaling, or flaking during freeze-thaw cycles than traditional mixes[x]. Salt scaling remains one of the largest concerns when slag accounts >25% of the mixture. When working around slag, additional care should be used to prevent unnecessary exposure to the skin, eyes, and lungs. Excessive, unprotected exposure to high concentrations of slag can cause coughing, sneezing, and respiratory inflammation, or silicosis if the slag has a high concentration of silica particles less than 5 microns in diameter.[xv] However, slag is not classified as a hazardous material[xiv], and the use of proper dust respirators minimize risk[xv].

Cost

Slag has the potential to reduce the costs of concrete mixes. A report for Sound Transit Authority in 2014 interviewed a number of concrete suppliers in the Pacific Northwest and found that the cost of using SCM will range from a 8% cost savings to a 3.5% cost premium. In most cases, using SCM reduces initial costs but like any commodity, the cost of these materials changes over time. Slag prices have historically trended along with cement prices (Sound Transit, Dec 2014).

Availability

Slag is procured either from Asian steel mills or Eastern US steel mills. Slag is not subject to the same potential supply challenges as fly ash and is regarded to have a stable supply chain.

Toxicity Concerns for SCM

There are concerns about the toxicity of fly ash and its use in concrete. Fly ash contains several chemicals of concern including numerous metals. While some of these compounds are also found in traditional Portland cement, the real question is whether they pose an unacceptable risk to human or ecological health. The Environmental Protection Agency (EPA) released a report titled "Coal Combustion Residual Beneficial Use Evaluation: Fly Ash Concrete and FGD Gypsum Wallboard" in February of 2014 (reference to this report here) that stated the use of fly ash in concrete does not pose a risk that is greater than the existing regulatory and health based benchmarks for human and ecological receptors. EPA concluded that they support the beneficial use of fly ash in concrete.

EPA's ruling was controversial among certain environmental groups that thought the scope of the analysis was exceedingly narrow and missed numerous exposure pathways (https://www.pharosproject.net/blog/show/182/epa-review-of-fgd-wallboard). Most notably, EPA did not examine the demolition and disposal risks associated with concrete. They studied exposure to dust during the "use phase" of concrete but didn't study the exposure to dust created by crushing concrete, a common practice used in recycling old concrete for backfill or road base.

Another major gap is that slag was not studied at all in EPA's evaluation. It's unclear whether the risks associated with using slag as an SCM have ever been evaluated. Overall, while the use of slag and fly ash appear to be safe while using concrete, there is still uncertainty about what, if any, additional risk is incurred during the demolition and crushing of concrete.

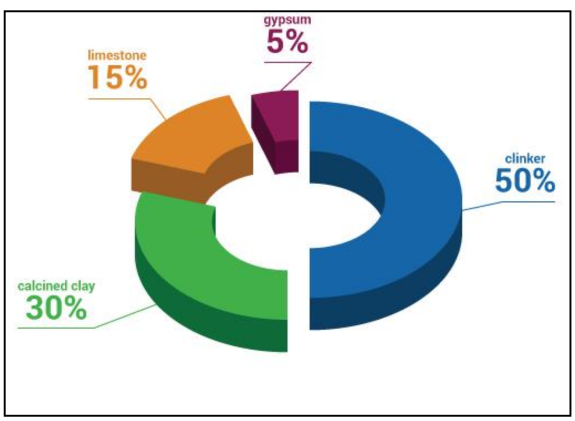
Further research should investigate the entire lifecycle of concrete and include both fly ash and slag.

Emerging methods to reduce the carbon content of concrete

All the methods described in this paper to reduce the carbon content of concrete focus on reducing the cement content in the concrete mix. The use of fly ash and slag are well established methods that have a proven track record and existing supply network. There are numerous other methods to reduce the cement content of concrete and this section will focus on just two of the emerging technologies.

Certain naturally occurring clays, known as kaolin or china clays, which are traditionally used to manufacture porcelain can also be used to produce a cement like pozzolanic material. The key mineral in these clays is called kaolinite. Different clays possess a wide range of kaolinite content that would be a suitable pozzolanic material. A pozzolan is a broad class of both naturally and manmade materials that have cementitious properties when combined with water and lime (calcium hydroxide). Both fly ash and slag are considered manmade pozzolans. Kaolin clays can be heated up to remove most of the adsorbed water and become a highly pozzolanic material that acts as an excellent SCM for concrete applications. This thermal activation process is also known as calcining (link to this reference). Koalin clays naturally occur all over the world but some areas have a much higher concentration of these clays than others (link here). There's a resurgence in this technology in recent years. Most notably, the efforts of the LC3, Limestone Calcined Clay Cement group, are starting to prove large scale production capactity of these clay based concrete in various locations in India, Cuba, and China (www.lc3.ch). Figure 7 below shows that using calcined clay as an SCM can reduce cement content by 50%, drastically lowering the carbon footprint of the concrete mix without introducing industrial waste products such as fly ash and slag.

Figure 7. Material components of Limestone Calcined Clay Cement.



Another emerging pozzolanic material is recycled glass. A limited number of companies are starting to crush glass into a fine powder-like silica substance that is regarded as a natural pozzolan and already approved for use by ASTM 618 – "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete" (reference link here). Glass is made from sand, which is an abundant natural resource. While there are few examples to draw from with this emerging technology, there seems to be great potential for recycled glass to be used in this manner. Recycling glass bottle into glass bottles can already be challenging in certain areas of the country that don't have strong glass recycling markets. Additionally, the cost to transport heavy glass to recycling markets can be cost prohibitive. Although there is little data to evaluate the concept of using recycled glass as a cement substitute, this use may be the highest and best use of recycled glass. Additionally, one company reports that their recycled glass SCM product is non-toxic and contains no crystalline silica or heavy metals (reference here).

Conclusion

Concrete is an abundantly used construction material that has substantial greenhouse gas impacts primarily caused by the production of cement. Fortunately, the concrete industry is already familiar with using supplementary cementitious materials (SCMs) such as fly ash and slag to reduce the cement content of concrete mixes. Reducing the cement content is the most effective strategy to lower the greenhouse gas impacts of concrete. In some markets, fly ash and slag are even less expensive than cement. One challenge to currently using fly ash and slag is its potential effects on the construction schedule. When used as a cement replacement over 30%, both fly ash and slag can have low early strength characteristics that may affect the project schedule if used for certain structural applications. Early construction planning and targeted specifications can help alleviate most of these drawbacks. Government purchasers have numerous strategies at their disposal for lowering the greenhouse gas impacts of concrete purchases. Overall, the concrete industry is actively developing and testing new supplementary cementitious materials to meet the demand for long lasting, low impact and safe concrete products. The strategies outlined in this paper will allow government purchasers to make meaningful reductions in their greenhouse gas impacts of their concrete purchases.

Case Studies

Concrete Case Study: I-5 Bridge Willamette River Bridge

The Oregon Department of Transportation, working with Knife River Corporation, Hamilton Construction, Slayden Construction, and OBEC Engineering, won a national award from the national Slag Cement Association in the High Performance category for the new Interstate-5 bridge over the Willamette River in Springfield, Oregon. Recognized alongside the new One World Trade Center tower in New York City, which tied for the award, the new bridge used a 60% slag concrete mix, previously never used by ODOT. This slag concrete is strong, with a compressive strength of 6,200 psi, much greater than the required strength of 4,500 psi requested in project specifications. Knife River Corporation provided 35,000 cubic yards of the slag concrete in the form of 12 different mix designs[1].

[i] The Loreti Group. 2008. "Greenhouse Gas Emission Reductions from Blended Cement Production" http://www.climateactionreserve.org/wp-content/uploads/2009/03/future-protocol-development_blended-cement.pdf
[ii] PCA. 2014. "How Concrete is Made." http://www.cement.org/cement-concrete-basics/how-concrete-is-made
[iii] Penn State College of Engineering. "Class C Fly Ash." http://www.engr.psu.edu/ce/courses/ce584/concrete/library/materials/Altmaterials/Class%20C%20Fly%20Ash.ht
[iv] Construction Specification Institute (CSI) Puget Sound Chapter. "The Greening of Concrete." http://psccsi.org/article-01/
[v] Headwaters Resources. "Fly Ash For Concrete." http://flyash.com/data/upfiles/resource/Fly%20Ash%20for%20Concrete%202014.pdf
[vi] Walsh. 2010. "Fly Ash in Building Products: Proceed with Precaution." http://www.healthybuilding.net/news/100915fly-ash-in-building-products.html
[vii] Vallette. 2014. "Buyers Beware: Coal Ash in Building Products." http://www.healthybuilding.net/news/2014/01/30/buyers-beware-coal-ash-in-building-products
[viii] ACAA. "Frequently Asked Questions of CCPs." http://acaa.affiniscape.com/displaycommon.cfm?an=1&subarticlenbr=5
[ix] SCA. 2002. "Concrete Proportioning." http://www.slagcement.org/Sustainability/pdf/No2_Proportioning.pdf
[x] FHWA. 2012. "User Guidelines for Waste and Byproduct Materials in Pavement Construction." http://www.fhwa.dot.gov/publications/research/infrastructure/structures/97148/bfs3.cfm
[xi] SCA. 2013. "Slag Cement and the Environment." http://www.slagcement.org/Publications/pdf/No22_Environmental_Benefits.pdf
[xii] SCA. "What are the Environmental Benefits of Using Slag Cement?" http://www.slagcement.org/News/FAQ_EnvBenifits.html
[xiii] America Ready Mix. 2007. "Slag Information." http://www.americanreadymix.com/Slag.html
[xiv] ToxStrategies. 2011. "Human Health Risk Assessment for Iron and Steel Slag." http://www.acobrasil.org.br/siderurgiaemfoco/CCABrasil/Human_Health_Risk_Assessment_for_Steel_Slag_1211.pdf
[xv] MSDS. 2008. "Steelmaking Slag." http://www.gerdauameristeel.com/products/msds/docs/mill-english/steelmaking%20slag%20msds%20(na)%2012-8-08.pdf
[xvi] America Ready Mix. 2007. "Slag Information." http://www.americanreadymix.com/Slag.html