LEED-NC™ 2.1 Guide:
Using Slag Cement in Sustainable Construction

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LEED-NC™ 2.1 Guide:
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Version 1.0

LIST OF TABLES

What is Slag Cement?

Slag cement, or ground granulated blast-furnace slag (GGBFS), has been used in concrete projects in the U.S. for over a century. Earlier usage of slag cement in Europe and elsewhere demonstrates that long-term performance is enhanced in many ways. Based on these early experiences, modern designers have found that these improved durability characteristics help further reduce life-cycle costs and lower maintenance costs.

When iron is manufactured using a blast furnace, the furnace is continuously charged from the top with oxides, fluxing material, and fuel. Two products—slag and iron—collect in the bottom of the hearth. Molten slag floats on top of the molten iron; both are tapped separately. The molten iron is sent to the steel producing facility, while the molten slag is diverted to a granulator. This process, known as granulation, is the rapid quenching with water of the molten slag into a raw material called granules. Rapid cooling prohibits the formation of crystals and forms glassy, non-metallic silicates and aluminosilicates of calcium. These granules are dried and then ground to a suitable fineness, the result of which is slag cement. The granules can also be incorporated as an ingredient in the manufacture of blended portland cement.

Slag cement remains the fastest growing cementitious material in the U.S., its use more than tripling since 1996. A record 3.5 million metric tons of slag cement were shipped for use in concrete and construction applications in 2004, a 16 percent increase over 2003.

What is LEED™?

Leadership in Energy and Environmental Design (LEED) is a national standard developed by the United States Green Building Council to certify high-performance, sustainable buildings. Currently, there are six LEED™ standards available for use or under development; however LEED-NC™, for new construction and major renovation, is the most widely used standard.[1]

LEED-NC™ utilizes a system where points are awarded for achieving specific levels of sustainable performance in six categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation in design.

Achieving LEED-NC™ Points with Concrete

Concrete is a superior material for building sustainable structures. Among its other attributes, it is durable, uses abundant, local materials in its manufacture, has high reflectivity for reduced urban heat island effect, and utilizes thermal mass to contribute to energy efficiency. In LEED-NC™ 2.1, the current version of the standard, concrete can contribute in whole or in part toward 25 points that contribute to LEED-NC™ certification.[2] At least 26 points are required for LEED-NC™ certification and a total of 69 points are available from all credit categories.

Making Concrete Greener with Slag Cement

Slag cement is a byproduct of iron production in a blast furnace. It is a hydraulic cement that can replace between 20 to 80 percent of the portland cement in concrete (depending on application, see Table 1) and helps makes concrete even greener. Slag cement contributes the following sustainability benefits to concrete:

- Reduces the virgin material used in the manufacture of concrete
- Reduces disposal
- Improves concrete strength and durability
- Reduces embodied energy
- Reduces embodied greenhouse gas emissions
- Increases concrete reflectivity

Benefits of Slag Cement at a Glance

Using slag cement to replace a portion of portland cement in a concrete mixture is a useful method to make concrete better and more consistent. Among the measurable improvements are:

- Better concrete workability
- Easier finishability
- Higher compressive and flexural strengths
- Lower permeability
- Improved resistance to aggressive chemicals
- More consistent plastic and hardened properties
- Lighter color

And, of course, slag cement can greatly improve the sustainable qualities of structures.

The Environmental Value of Slag Cement – Quantified

The 3.5 million metric tons of slag cement used in 2004 represents the following environmental benefits:

- Avoided carbon dioxide emissions: 3.0 million metric tons (the equivalent carbon emissions produced by 500,000 cars)
- Avoided energy use: 15.0 trillion BTUs (the equivalent total energy used by 71,000 households)
- Raw material savings: 5.2 million metric tons (the equivalent raw material needed to make portland cement for 2,700 lane-miles of concrete pavement).

Table 1 – Suggested Slag Cement Replacement Levels

Concrete Application	Slag Cement*
Concrete Paving	25-50%
Exterior flatwork not exposed to deicer salts	25-50%
Exterior flatwork exposed to deicer salts with w/cm ≤ 0.45	25-50%
Interior flatwork	25-50%
Basement floors	25-50%
Footings	30-65%
Walls and columns	25-50%
Tilt-up panels	25-50%
Prestressed concrete	20-50%
Precast concrete	20-50%
Concrete blocks	20-50%
Concrete pavers	20-50%
High-strength concrete	25-50%
Alkali-silica reaction mitigation	25-70%
Sulfate resistance	
Type II Equivalence	25-50%
Type V Equivalence	50-65%
Lower permeability	25-65%
Mass concrete (heat mitigation)	50-80%

** Percentages indicate replacement for portland cement by mass. These replacement rates are recommended for individual applications and are based on historical performance. Variations in material sources and environmental conditions may require alternate substitution rates. Consult your slag cement supplier for additional assistance. As with all concrete mixtures, trial batches should be performed to verify concrete properties. Results may vary due to a variety of circumstances, including temperature and mixture components, among other things. Nothing contained herein shall be considered or construed as a warranty or guarantee, either expressed or implied, including any warranty of fitness for a particular purpose.*

Using Slag Cement to Help Achieve LEED-NC™ Certification

Table 2 summarizes the credits where slag cement can contribute to achieving points in accordance with LEED-NC™, Version 2.1. The sections following the table provide guidance to project teams in properly planning for and calculating the point contributions of slag cement.

TABLE 2: SUMMARY OF LEED-NC™ CREDITS AND POINTS WITH POTENTIAL SLAG CEMENT CONTRIBUTION

Category	Credit	Description	Possible Points
Sustainable Sites	SS 3	Brownfield Redevelopment	1
Sustainable Sites	SS 7.1	Heat Island Effect: Non-Roof	1
Materials and Resources	MR 1.1	Maintain 75 Percent of Existing Walls, Floors and Roof	1
Materials and Resources	MR 1.2	Maintain 100 Percent of Existing Walls, Floors and Roof	1
Materials and Resources	MR 4.1	Recycled Content: 5 Percent (Post Consumer and 1⁄2 Post-Industrial)	1
Materials and Resources	MR 4.2	Recycled Content: 10 Percent (Post Consumer and 1⁄2 Post-Industrial)	1
Materials and Resources	MR 5.1	Regional Materials: 20 Percent Manufactured Regionally	1
Materials and Resources	MR 5.2	Regional Materials: 50 Percent Extracted Regionally	1
Innovation in Design	ID 1.1	Credit Interpretation Ruling IDc11, Reduction of Total Portland Cement Content for Cast-in-Place Concrete	1

Sustainable Sites Credit SS 3 – Brownfield Redevelopment *(1 Point)*

This credit is intended to encourage redevelopment of sites where real or perceived environmental contamination has taken place. Often a brownfield site contains soils that were contaminated with hazardous organic compounds and/or heavy metals by industrial processes. In-situ stabilization and solidification of these soils is a method recognized by the Environmental Protection Agency to reduce toxicity and leachability.[3] Slag cement can serve as one of the binder materials in the stabilization/solidification process.[4] To achieve this credit, the site must have documented contamination or be classified as a brownfield by a public regulatory agency. A site remediation plan must be developed and implemented, with a signed LEED™ Letter Template certifying that the contamination has been successfully remediated.

Sustainable Sites Credit SS 7.1 – Heat Island Effect: Non-Roof *(1 Point)*

This credit is intended to minimize urban heat islands, where microclimate temperatures are raised in developed areas, contributing to increased energy use and adverse health affects associated with elevated smog and ground level ozone. One of the ways to achieve this credit is to use light-colored (high-albedo) materials with a reflectance of at least 0.3 for at least 30 percent of the site's non-roof impervious surfaces. New concrete made with gray portland cement will typically have an albedo of between 0.35 and 0.40, while weathered concrete will be between 0.20 and 0.30. Slag cement is a very light material, much lighter than portland cement, fly ash or silica fume, and will improve both the new and weathered albedo of the concrete.[5-7] Slag cement can increase the reflectivity of concrete (versus ordinary portland cement concrete).[8] Asphalt pavements, on the other hand, typically have an albedo of between 0.05 and 0.15. A LEED™ Letter Template must be provided that references and documents the high-albedo non-roof surfaces (type, quantity, and solar reflectance).

Albedo (solar reflectance) is most commonly measured using a solar reflectometer (ASTM C1549) or a pyranometer (ASTM E1918). The solar reflectometer, ASTM C1549, "Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer," is usually done by a laboratory using a sample in the range of 2 to 5 sq in (1500 to 3000 sq mm). The pyranometer, ASTM E 1918, "Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field," is performed in the field on surfaces at least 13 ft (4 m) in diameter. Measurements are done on a sunny day when the angle of the sun to the earth's surface is greater than 45 degrees. For northern cities like Chicago, the best time to take measurements is April through August. The concrete surface finish affects albedo, with a rougher finish lowering the value. The same finish as will be

Slag Cement Helps Make a Brownfield Green Again

In Appleton, Wisconsin, We Energies is taking sustainability seriously, bringing new life to the former site of a manufactured gas plant (MGP). Located next to the Fox River Canal, the plant was closed in the 1950s, leaving behind contaminated land. We Energies opted to use soil stabilization/ solidification (S/S) to restore the land for public use.

S/S is a process that immobilizes contaminants, mitigating the risk of exposure and potential harm to human health and the environment. Cement material is mixed with impacted soil and hardens to form a soil-cement matrix that encapsulates the impacted materials. In this case, the process was performed on site soils in-place, otherwise known as in-situ stabilization/solidification (ISS).

Before work began, Compass Environmental (known then as Williams Environmental Services) performed a treatability study. The company has used slag cement in its ISS mixes for the past four years. "The material has recently gained a lot of acceptance because of noticeably increased compressive strengths and lower permeability," explains Jim Brannigan, project manager with Compass. "The treatability study showed it to have a far superior performance over other additives, and because we're able to utilize it like portland cement, we didn't have to change any of our equipment."

The team developed three mix designs, including one that blended 25 percent portland cement and 75 percent slag cement. In all, more than 35,000 cu yd of material was stabilized. The

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method is so reliable that Compass Environmental evaluates slag cement for use on almost every S/S project and many different contaminants such as petroleum-based products, pesticides and heavy metals.

Although this project did not result in any LEED-NC™ certification (no buildings have been developed on the site), the ISS technique with slag cement could be employed to transform other brownfields into potential building sites. This would qualify for a point under Sustainable Sites Credit SS3, Brownfield Redevelopment.

used on the in-place concrete is recommended. Also, the curing and drying time affect albedo. Concrete should be allowed to dry a sufficient time before testing.

Materials and Resources Credits MR 1.1 and MR 1.2 – Maintain 75 and 100 Percent of Existing Walls, Floors and Roof *(1 Point Each Credit)*

These credits are intended to extend an existing building's life, conserve resources, and reduce waste by reusing the shell of an existing building. Slag cement has the potential to extend a concrete structure's life (if it was used in the original concrete in the structure) because it improves concrete durability. Slag cement increases concrete corrosion resistance and increases the resistance to harmful chemical attack such as expansions from reactive aggregate and sulfate attack. While the use of slag cement in new concrete produced for a current project will not contribute to the MR 1.1 and MR 1.2 points achievable immediately, slag cement concrete can help with building reuse if the building's function or intended use changes. This becomes an especially important consideration when concrete will be exposed to aggressive environments, such as seawater, sulfate-bearing soils, deicer salts and reactive aggregates in concrete. Methods of estimating concrete life cycle are provided in reference 9.

Materials and Resources Credits MR 4.1 and MR 4.2 - Recycled Content: 5 and 10 percent (Post Consumer and 1⁄2 Post-Industrial)
(1 Point Each Credit)

The intent of these credits is to promote use of building products that include recycled content materials, thus reducing the effects of extraction/processing of virgin materials. This credit is calculated by determining if the sum of post-consumer recycled content and 1⁄2 of the post-industrial content is at least 5 percent (for credit 4.1) or 10 percent (for additional credit 4.2) of the total value of the materials in a project. Slag cement will contribute toward the recycled content credit as a post-industrial material.

To calculate slag cement's contribution, a breakdown of concrete mixture materials must be detailed. As an example, assume 5,000 cubic yards of concrete were used for reinforced concrete beams and columns at a cost of $60 per cubic yard using the mixture proportions in Table 3.

Through Harsh Winter, Slag Cement Speeds Construction in Manhattan

High-rise residential project winning accolades for being green

The Helena – 601 W. 57th – Manhattan, New York

Located in the heart of Manhattan at the corner of West 57th and 11th, The Helena is a 600,000-square-foot residential development that will offer 597 rental apartments, street-level commercial space and underground parking. The building team on the 38-story reinforced concrete frame structure hopes to earn a Gold Certification in the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Rating System, and is using a 45 percent slag cement concrete mix to achieve that goal.

Under LEED guidelines, building teams can earn credits for using recycled content and incorporating materials that are harvested or manufactured locally—two benefits slag cement concrete offers. The Helena's owner, The Durst Organization (Manhattan, NY), is not only aiming for LEED certification, but also savings through the New York State Green Building Tax Credit. Passed in 2000, the credit will reward projects that meet "green" building standards of energy efficiency, good indoor air quality and an overall reduction in environmental impact.

High early strengths were a priority on this project, which hinged on two-day construction cycles

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TABLE 3 – EXAMPLE OF CONCRETE RECYCLED CONTENT WITH SLAG CEMENT

Concrete Component	Weight (lb/cubic yard)	Recycled Content	Percent by Weight
Slag Cement	284	100%	7.1%
Portland Cement	284	0%	7.1%
Aggregate	3200	0%	79.9%
Water	237	0%	5.9%
Total	4005		100%

Value of concrete recycled content is then calculated as follows:

Total value of concrete = 5000 cy x $60/cy = $300,000
Contribution toward recycled value = $300,000 x 7.1% x 0.5 (for post-industrial) = $10,650

This amount ($10,650) is then added to all the other building component recycled costs for a total cost of recycled materials. This sum is then divided by the total cost of all the materials (including the $300,000 for the example concrete) on the project. If the result is at least 5 percent, then 1 point for MR Credit 4.1 is earned. If the result is at least 10 percent, then an additional 1 point for MR Credit 4.2 is earned.

Materials and Resources Credit MR 5.1 and MR 5.2 – Regional Materials: 20 Percent Manufactured Regionally (4.1) and 50 Percent Extracted Regionally (4.2) *(1 Point Each Credit)*

The intent of this credit is to decrease transportation of materials to a building project by using materials that are extracted and manufactured within the region close to the project, thereby reducing the environmental effects of transportation and supporting the local economy. To receive a point for MR 5.1, a minimum of 20 percent of building materials must be manufactured within a 500-mile radius of the building project. For concrete, the point of manufacture will be the plant where the concrete is batched, typically a ready-mixed concrete plant, but sometimes on-site (no matter where the component materials—aggregate, portland and slag cements, admixtures—originated). Virtually all concrete delivered to a construction project in the plastic state will be manufactured within a 500-mile radius. Precast concrete is also often manufactured

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that couldn't afford significant slowdowns as temperatures dropped. Jim Werner, sales representative for slag cement supplier Lehigh Cement, says the team achieved a one-day break higher than 5,000 psi from what he calls "a real high-octane mix" with 45 percent slag cement. "We knew it would work, we just didn't know how well it would work." Even in harsh winter conditions, "With the mix we're using now, we're seeing the benefit of slag cement at one to three days, instead of the usual seven to 28 days."

The Helena also incorporates numerous sustainable features, and some of the units are being offered as affordable housing. All of this combined to help the project win the 2005 "Show Your Green" Program Award, given by the American Institute of Architects Housing Committee.

within a 500-mile radius; its point of origin is the precast manufacturing plant. The local/regional manufacturing rate is calculated as follows:

Local Mfg. Rate, % = (Cost For All Locally Mfg Mat'ls, $) / (Total Mat'ls Cost, $)

To achieve a point for MR 5.2, at least 50 percent of the locally manufactured materials (in MR 5.1) must have been extracted or recovered locally. For concrete, the point of extraction or recovery and the costs for each of the constituent materials must be documented and separated into portions (by cost) inside and outside the 500-mile radius. Often, the extraction/recovery points for all concrete ingredients are within the 500-mile radius. However, some materials—particularly the higher value materials such as portland and slag cements—may have a point of origin beyond the 500-mile radius. For slag cement, the point of material recovery is the iron blast furnace/slag granulation facility. Most slag cement used in the U.S. is recovered from iron blast furnaces located within North America; however, some slag is imported from outside the continent. The slag cement supplier can provide the point of origin for its material supplied for local concrete manufacture. SCA's web site provides a map of North American iron blast furnaces/slag granulation facilities (www.slagcement.org > member info > facility maps), as well as local office contacts for SCA member slag cement supplier (www.slagcement.org > member info > where to get slag cement). The local/regional extraction rate, as a percentage of locally manufactured materials, is calculated as follows:

Local Extraction Rate, % = (Cost for All Locally Extracted Mat'ls, $) / (Cost for All Locally Mfg Mat'ls, %)

For both the MR 5.1 and 5.2 credits, a LEED™ Letter Template must detail the calculations involved in determining these percentages including costs, percentage of local components, distance from project to manufacturer, and total cost of all materials for the project.

One item of note in achieving MR 5.1 and 5.2 credits is that slag cement can sometimes help utilize local materials in lieu of materials that must be transported from a further distance. Two specific examples are:

1. **Alkali-Silica Reaction (ASR):** Some aggregates contain silica compounds that react with the alkalis in portland cement to produce expansion in the concrete. Sometimes specifiers choose to transport non-reactive aggregates from a much further distance. However, if the proper percentage of slag cement is chosen in the concrete (and verified through testing), the ASR is mitigated, and local reactive aggregates can be used. See reference 10 for more guidance.

2. **Sulfate Attack:** External sulfates found in some soils, seawater, wastewater treatment plants and other industrial processes can cause serious damage to concrete not properly proportioned using sulfate-resistant cements. Type II and Type V portland cements provide moderate and high sulfate resistance for various environments. However, sometimes sulfate-resistant cement, particularly Type V, is not locally available. Slag cement can be highly effective when properly proportioned in concrete in mitigating sulfate attack using a locally available Type I (or II) portland cement. See reference 11 for more guidance.

Innovation in Design Credit – ID 1.1 – Reduction of Total Portland Cement Content for Cast-in-Place Concrete *(1 Point)*

Innovation in Design credits are intended to provide project teams the ability to achieve exceptional performance above LEED-NC™ minimums, or to address innovative performance not currently covered by LEED-NC™. Requests for credit interpretations are submitted to the USGBC in writing, identifying the intent of the proposed credit, the proposed requirement for compliance, proposed submittals, and design approach to meet the requirements.

A specific Innovation in Design credit has been approved by the USGBC to allow one point for a 40 percent minimum reduction of carbon dioxide by weight for all cast-in-place concrete against baseline mixtures.[12] To achieve the point, cast-in-place concrete must constitute a significant portion of the project.

To calculate whether or not the credit is met, calculations shall assume the following:

- One pound of portland cement is equivalent to one pound of carbon dioxide
- Baseline mixtures shall be standard, 28-day strength regional mixture designs
- Temperature range shall be accounted for and documented
- Documentation for cold weather mixture designs shall include temperature on day of placement
- Slag cement and other recovered cementitious materials such as fly ash and silica fume are allowed for displacement of portland cement

Slag Cement Scores High for Clearview Elementary School

2004 SCA Award: Best Use of Slag Cement for Sustainable Construction

Clearview Elementary School in Hanover, PA, is showing how slag cement makes the grade in institutional construction. It was built with insulating concrete forms (ICFs), a building system consisting of foam forms stacked in the shape of the structure. The ICFs are filled with steel-reinforced concrete to create a solid wall with excellent thermal mass, strength and durability. The ICFs are a prime design element that will help achieve a one-third reduction in energy consumption, compared with a conventional structure.

The LEED-NC™ Gold-certified project opened to students in January 2003, and Principal Josephine Bookwalter says the new school has made a huge impact: "Students and staff are better at focusing on learning rather than the environment," she says. John Boecker, lead architect on the project with L. Robert Kimball & Associates, adds, "We set out for Clearview to be a place where students thrive and parents and taxpayers get the most for their money, both up-front and over the life of the building."

Scot Horst, project consultant and principal of 7group, says an innovative concrete mixture design was key in achieving LEED-NC™ Gold certification. The concrete incorporated a high slag cement content, as much as 60 percent of cementitious material in the ICFs. A member of the U.S. Green Building

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Council's materials and resources technical advisory group at the time of the project, Horst pushed for creation of an Innovation and Design Credit to assist in LEED-NC™ certification, paving the way for other project designers to earn similar credits for innovative concrete mixtures. The Credit recognizes reduction of greenhouse gases through replacement of portland cement in concrete, rewarding designs that demonstrate a minimum of 40 percent reduction by weight for cast-in-place concrete.

In all, approximately 40 percent of the building material for the project was manufactured locally, and about 75 percent (by cost) was manufactured with a high recycled content. With many additional energy-efficient design components, the school will save an estimated $34,000 annually on energy costs.

The following documentation is required:

- Total volume (cubic yards) of cast-in-place concrete on the project
- Standard 28-day strength concrete mixture designs from the concrete producer, in accordance with ACI 301, for each concrete mixture used
- Quantity of portland cement for each mixture in pounds per cubic yard
- Temperature on day of concrete placement if a cold weather mixture is used
- Calculation demonstrating that a minimum of 40 percent average reduction has been achieved over standard concrete mixture designs for all cast-in-place concrete

Using slag cement in concrete helps achieve the ID 1.1 credit, as typical mixtures can utilize between 25 and 80 percent slag cement as a portion of cementitious material (see Table 1 for guidance). Reductions in embodied greenhouse gas emissions and energy are documented in an SCA report detailing the life cycle inventory of slag cement concrete in typical concrete mixtures for cast-in-place concrete, as well as precast concrete and block.[13] Reference 12 shows that one pound of slag cement embodies 0.021 lb CO2 (approximately 10 grams). Specific strategies for achieving this credit are detailed in Table 4.

To employ the strategies listed above, the project design and construction team, as well as the concrete supplier, must work closely together to develop reasonable concrete specifications, and mixtures that meet those specifications in the anticipated environmental conditions. Using higher levels of slag cement will generally provide benefits such as improved workability and consolidation, better slump retention and longer working time, increased ultimate strength, significantly lower permeability, improved resistance to corrosion and chemical attack, and a lighter color. Although concrete containing slag cement is constructed the same way as ordinary portland cement concrete, using higher levels of slag and/or lower cementitious contents may increase concrete time of set (affecting finishing time), decrease early strength (affecting form stripping, early loading and time to saw cut), and change the timing and amount of bleed water formation. Appropriate adjustments must be made to account for these differences, and guidance can be found in references 14 through 22.

Specifications

Slag cement as a material batched separately at a concrete plant can be specified by citing ASTM C989.22. Also, blended cement containing both portland and slag cement components can be specified by citing ASTM C595.23, Type

Life Cycle Analysis and Inventory

Quantifying the Sustainability Improvements of Slag Cement

A life cycle assessment (LCA) is a systematic evaluation of a product's or system's environmental impacts, from cradle to grave. Ideally, an LCA can be used by building professionals to evaluate the total environmental impacts of a building through its life cycle, and can be used as a tool to compare alternative designs, products and processes. An LCA consists of three phases: inventory, impact assessment and evaluation.

The life cycle inventory (LCI) phase of LCA is currently the only phase with a well-defined methodology. An LCI details, for a product or process, 1) energy use; 2) raw material and fuel use; and 3) air, solid and liquid waste pollutant generation. LCI procedures have been standardized in ISO 14040 and 14041.

Although LEED-NC™ 2.1 does not currently incorporate LCA or LCI in its point system, development of future versions of LEED are anticipated to include some form of LCA.

The SCA has developed ISO-compliant LCI data for slag cement shipped in the U.S. Combining this data with LCI information from other components of concrete (e.g. portland cement, coarse and fine aggregate, fly ash), results in LCIs for a variety of concrete mixtures.

Utilizing slag cement to substitute for a portion of the portland cement in concrete is a great way to

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I(SM) for slag percentage below 25 percent, or Type IS for slag percentage 25 percent and above. More guidance on specifications can be found in references 24 and 25.

Additional Resources

The table below details potentially useful resources and references for project teams considering using slag cement to help achieve LEED-NC™ points.

Table 4 – Strategies and Methods of Achieving Average 40 Percent Reduction In Portland Cement Use with Slag Cement Concrete

Strategy	Method
Substitute appropriate amounts of slag cement for portland cement	Utilize Table 1 to help choose a slag cement percentage high enough to achieve an average 40 percent portland cement reduction (which yields an approximate 40 percent reduction in greenhouse gasses), but that also meets other requirements for the intended application (e.g. strength, permeability, resistance to chemical attack, cold weather effects). The credit is based on the "average" reduction in portland cement, so not all mixtures need to achieve a 40 percent reduction. For instance, massive foundations requiring heat mitigation could use up to 80 percent slag cement[17] (and may constitute a high volume of project concrete); structural beams and columns could use up to 50 percent slag cement (early strength requirements must be monitored); insulated concrete forms could use 60 percent slag cement; post-tensioned slabs, typically requiring high-early strength, might use 20 percent slag cement.
Decrease total cementitious material content to achieve 28-day strength	Slag cement will typically achieve higher strengths beyond 7 to 10 days than ordinary portland cement concrete, so generally the 28-day design strength of concrete containing slag cement will be higher than an

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conserve a valuable resource: portland cement. In many everyday concrete mixtures slag cement can replace between 25 to 50 percent of the portland cement (and up to 80 percent in special applications, such as mass concrete). Due to this high substitution rate, the LCI of concrete that includes slag cement quantifies a substantial savings in raw materials, embodied energy, and greenhouse gas production. For instance, a typical concrete mixture, proportioned for 5,000 psi compressive strength, can achieve the following reductions:

- Raw material savings – 10 percent or about 250 lb per cubic yard of concrete
- Energy savings – 37 percent or about 560,000 btu per cubic yard of concrete
- Greenhouse gas savings – 45 percent or about 250 lb per cubic yard of concrete

These LCI savings figures help quantify the environmental benefits of using slag cement in concrete.

Table 4 – Strategies and Methods of Achieving Average 40 Percent Reduction In Portland Cement Use with Slag Cement Concrete

Strategy	Method
	equivalent mixture containing only portland cement. Mixtures that are proportioned to meet 28-day strength specifications may be able to meet these specs with a reduced amount of total cementitious material. However, as total cementitious material is reduced, early strengths will be reduced, so care must be taken to ensure adequate strength for early loading requirements. Additionally, other criteria (if applicable), such as permeability, resistance to chemical attack, and cold weather effects, must be considered.
Increase the number of days required to achieve design strength to reduce total cementitious material content	Typically, specifiers call for a minimum 28-day strength in concrete. Not only does slag cement concrete generally achieve higher 28-day strengths, but the strength continues to increase at a more rapid pace beyond 28 days than an equivalent portland cement concrete mixture. If the number of days is increased (potentially up to 90 days, depending on application), the mixture may not need as much cementitious material to achieve the required strength. However, as total cementitious material is reduced, early strengths will be reduced, so care must be taken to ensure adequate strength for early loading requirements. Additionally, other criteria (if applicable), such as permeability, resistance to chemical attack, and cold weather effects, must be considered.
Utilize ternary mixtures to achieve project requirements	Sometimes using three cementitious materials (ternary mixtures) can be useful in achieving project objectives. Portland/slag/silica fume and portland/slag/fly ash mixtures are typical ternary examples. Slag cement is completely compatible with silica fume and fly ash.[21]

Table 4 – Strategies and Methods of Achieving Average 40 Percent Reduction In Portland Cement Use with Slag Cement Concrete

Strategy	Method
	A portland/slag/silica fume mixture may be useful in a high ultimate strength application where higher early strength is also required. A portland/slag/fly ash mixture is an alternative when the designer wishes to utilize a local fly ash, but is limited by the amount of fly ash substitution in everyday mixtures. Additionally, portland/slag/fly ash mixtures provide an alternative to "high-volume fly ash" mixtures that attempt to use fly ash substitution levels greater than about 30 percent. For example, concrete producers and contractors will generally find that a mixture containing 50/35/15 percent portland/slag/fly ash will be substantially easier to design, produce and place than one containing 50/50 percent portland/fly ash.

Table 5 – Resources and References

Ref # (from text)	Title	Author(s)/Organization	Source/Report/Year
1	Green Building Rating System for New Construction & Major Renovations (LEED-NC™), Version 2.1	U. S. Green Building Council	November 2002, Revised 3/14/03
2	Building Green with Concrete; Points for Concrete in LEED™ v2.1	Portland Cement Association	IS312, 2005
3	Stabilization/Solidification of CERCLA and RCRA Wastes	U. S. Environmental Protection Agency, Center for Environmental Research Information and Risk Reduction Engineering Laboratory	EPA/624/6-89/022,1989
4*	Waste Stabilization and Solidification Using Slag Cement	Slag Cement Association	SCIC** #26, 2005
5	R&T Update: Albedo: A Measure of Pavement Surface Reflectance	American Concrete Pavement Association	No. 3.05, June 2002
6	Shining a Light on "Cool Communities"	Environmental Council of Concrete Organizations	EV19, 1999
7	A Bright Idea: Specify Concrete	Environmental Council of Concrete Organizations	EV24, 2001
8	Slag Cement and the Environment	Slag Cement Association	SCIC #23, 2002
9*	Slag Cement and Life Cycle Prediction Models	Slag Cement Association	SCIC #23, 2003
10*	Mitigating Alkali-Silica Reaction	Slag Cement Association	SCIC #8, 2002
11*	Mitigating Sulfate Attack	Slag Cement Association	SCIC #7, Rev 1, 2005
12	LEED™ Innovation & Design Process Credit Interpretation IDc11 for reducing total portland cement content of cast-in-place concrete	U.S. Green Building Council	CIR IDc11, 1/23/2003

Table 5 – Resources and References (continued)

Ref # (from text)	Title	Author(s)/Organization	Source/Report/Year
13*	Life Cycle Inventory of Slag Cement Concrete	Prusinski, Marceau and VanGeem	Eighth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Supplementary Papers, 2004
14*	Concrete Time of Set	Slag Cement Association	SCIC #3, 2002
15*	Saw Cutting Joints	Slag Cement Association	SCIC #4, 2002
16*	Producing and Placing Slag Cement Concrete	Slag Cement Association	SCIC #5, 2002
17*	Reducing Permeability	Slag Cement Association	SCIC #6, 2002
18*	Reducing Thermal Stress in Mass Concrete	Slag Cement Association	SCIC #9, 2002
19*	Slag Cement and Fly Ash	Slag Cement Association	SCIC #11, 2003
20*	Compressive and Flexural Strength	Slag Cement Association	SCIC #14, 2003
21*	Ternary Concrete Mixtures with Slag Cement	Slag Cement Association	SCIC #20, 2003
22	ASTM C989, Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars	ASTM International	ASTM C989-05, 2005
23	C595, Standard Specification for Blended Hydraulic Cements	ASTM International	ASTM C595-03, 2003
24*	Terminology and Specifications	Slag Cement Association	SCIC #12, 2003
25*	Suggested Specification Provision for Slag Cement Concrete	Slag Cement Association	SCIC #13, 2003

** Available on www.slagcement.org   ** SCIC – Slag Cement in Concrete/Construction series of information sheets*

Useful Web Sites

www.slagcement.org....................Slag Cement Association
www.usgbc.org....................U.S. Green Building Council
www.astm.org....................ASTM International
www.ecco.org....................Environmental Council of Concrete Organizations
www.nrmca.org....................National Ready Mixed Concrete Association
www.cement.org/concretethinking....................Portland Cement Association, Sustainable Development
www.cement.org....................Portland Cement Association
www.epa.gov/epaoswer/non-hw/procure/index.htm....................U.S. EPA, Comprehensive Procurement Guidelines
www.epa.gov/swerosps/bf/index.html....................U.S. EPA, Brownfield Development
www.epa.gov/greenbuilding/....................U.S. EPA, Green Building

Slag Cement Helps Build a More Sustainable Community

Affordable—and green—residential project a good fit for Harlem

1400 Fifth Avenue Millennium Housing Project – Harlem, New York

Billed as Harlem's first affordable "green" and "smart" building, the 1400 Fifth Avenue Millennium Housing Project offers 128 condominium units and eight interior retail spaces. More than 60 percent of the building is constructed using materials that are either recycled or recyclable, and the building will consume 25 percent less energy than is required by the New York State Energy Code. The development is designed with moderate- to middle-income families in mind, and is the largest affordable, green residential development in the U.S.

One of the materials making the project possible is slag cement, which comprises 10 percent of the concrete mix used in the building's foundation and some concrete masonry units for attached townhouses. Carlton Brown, COO for owner Full Spectrum of New York, LLC, says the decision to use slag cement was "100 percent due to LEED certification," and that the project team is aiming for a Gold LEED certification.

"Slag cement was really important for us on recycled content," says Brown. To qualify for LEED certification and the New York State Green Building Tax Credit, the structure had to have a high recycled content. "We focused on strategies that didn't cost any more," says Brown. "The slag cement strategy didn't cost any more, and yet has a huge positive environmental impact." Slag cement also contributed to a solid foundation that meets high strength standards of 3,500 psi—another way the building contributes to sustainable development.

Incorporating newer green building approaches can be challenging in the U.S. market, Brown says. Jude Alibey, Full Spectrum's in-house senior project manager, had worked with slag cement on projects outside the U.S. and was able to smooth the way for its use. In Brown's experience, more builders are beginning to embrace sustainability—especially when there is a financial reward. "With the New York State tax credit, there's a financial benefit, and that gets our attention. It gives us an edge."

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