

Establishing Third-Party Certification for Sustainable Building Materials

***Lindsey Maclise, P.E., LEED AP; Allen Nudel, S.E., LEED AP; Co-Chairs
SEAONC Sustainable Design Committee
San Francisco, CA***

Abstract

Buildings account for over a third of the environmental impacts in the United States and around the world. With state and national environmental goals such as the 2030 Challenge and California's Assembly Bill 32, it is imperative that aggressive measures are taken in all aspects of building design. The construction industry is currently making the move from conventional design to "sustainable design", with the ultimate goal of "net-zero design"- a step which will require the Architectural, Engineering and Construction (AEC) industry to take a fresh look at traditional practice. As part of the construction industry, structural engineers are expected to do their part to help achieve these goals.

In the 1990's, the wood industry began working hard to enable specifiers of lumber to require higher environmental impact standards. The not-for-profit and non-governmental Forest Stewardship Council (FSC) has been a model for how an industry can revolutionize resource management and reduce environmental impacts, on a purely volunteer basis, and maintain product demand.

While the concrete and steel industries have made large strides in reducing the environmental impacts of their products over the last couple of decades, there is currently no independent third-party certification for these materials in a similar method to the wood industry.

Using FSC and the wood industry as an example, this paper will serve to demonstrate the need for both the concrete and steel industries to adopt independent third-party certification systems. The requirements of this system may include metrics such as carbon dioxide reduction, responsible mining, greater efficiencies in production, pollution reduction, and fair treatment of people. By enabling owners, structural engineers and builders to select and specify products that meet stricter environmental protection requirements, an independent third-party certification system will bring us one step closer to achieving our "net-zero" goals.

Acknowledgements

This paper is a result of the collaborative efforts of the SEAONC Sustainable Design Committee. The co-chairs of the committee assembled this paper with the extensive help of our editors Kate Coffaro, Megan Stringer and Sandy Hohener as well as the contributions of Philip Bastiao, Matthew Kyler, Lisa Minakami, Sabina Shiu, Petra Patton, Stephen Bono, Erik Kneer, Lisa Podesto, Steve Patton, Won Lee and Chris Petteys.

Introduction

Wood is currently the only structural building material subject to a third-party verification system to demonstrate environmental responsibility. The third-party certification systems established for wood aim to protect indigenous people's rights, encourage fair trade, improve treatment of local communities, and set environmental management goals for long term sustainability. The certification systems used in the wood industry have requirements and incentives for the wood industry to demonstrate sustainability, but such incentives do not exist for the steel and concrete industries.

In reviewing the structural materials used in buildings, one must look at the entire life cycle and sourcing of these materials. For concrete, the sourcing of the cement and aggregate, the efficiencies of cement and concrete plants, the fuel sources used in the plants, and many other phases of the material's development should be reviewed. For steel, the sourcing of the ore, the energy efficiency of mills, and the amount of energy utilized to fabricate the steel all must be considered in determining the sustainability of the material.

This paper begins by reviewing the current practices of the wood industry, how these standards were established, and the economic impacts of certification. Utilizing the model of the wood industry, the current status of the concrete and steel industries is examined. This paper then considers how the materials are currently extracted, reviews production processes, and explores opportunities for improvement. Lastly, recommendations are provided for how the steel and concrete industries can improve to achieve long term sustainability goals. Ultimately the success of these recommendations is dependent on the concrete and steel

industries embracing these ideas and establishing voluntary regulation standards which can be monitored by independent third-party auditors.

History of Wood Certification

In the early 1990's, the Forest Stewardship Council (FSC) and the Sustainable Forestry Initiative (SFI) systems were developed to regulate the sustainable production of wood. Forest certification was initially introduced to reduce deforestation in tropical regions and to ensure responsible forest management, as well as to promote practices that are environmentally, socially, and economically sustainable over the long term. These systems were later applied to all types of forests.

The voluntary non-profit FSC organization was established through collaboration between leading environmental groups, grassroots social organizations, and industry representatives in 1993 following a United Nations Conference on the Environment and Development. In the U.S., FSC quickly gained popularity due to public demand for more sustainable wood products. As demand increased, companies such as specialty retailer Home Depot became early adopters of FSC and announced that most of its wood products would come from certified sources (MacDonald, 2011).

In 1995, the SFI was formed as an alternative to FSC in the U.S. SFI later became a non-profit independent organization and established a diversified board with representation from conservation organizations. As a result, the wood industry has two competing third-party certification systems that drive the industry forward.

Current Wood Certification Process

The main type of certification system used by the wood industry is a "Performance-Based Approach", which is utilized by both FSC and SFI. In this system, the wood supplier or manufacturer applying for certification of its product must meet certain standards set by its certifying organization (Hansen, 2006). All major wood certification systems following the Performance-Based Approach have third-party auditors, chain of custody standards, public reporting, stakeholder consultations, independent governance, and on-product labeling (Fernholz, 2010). Independent organizations typically act as third-party auditors for these certification systems and grant certificates of compliance (Guillery, 2004).

In general, when a landowner or manager is seeking forest certification, the first step is to choose an accredited certifier. Proposals may be requested from multiple third-party certifiers to generate bids. The chosen certifier then performs

an on-site assessment and issues a report detailing any deficiencies that require corrective action to meet the program standards. Once the report is official, it is made available as a public document. (Guillery, 2004)

Cost is often an issue for wood producers wishing to certify their forest or products, particularly for small business owners. Many certification programs offer the opportunity for small land owners to group together under one assessment thus reducing costs (Hansen, 2006). Non-governmental organizations, cooperatives, and land owner associations can also oversee group certification. Instead of individual audits, the auditor reviews one area of land that is managed by a common organization or consultant and assumes all forests in the group meet such standards. This type of system allows smaller producers to achieve certification at reduced costs, a method which could be utilized by the steel and concrete industries to assist small businesses when establishing third-party certification requirements and procedures.

Importance of Chain of Custody Certification

One of the important aspects of wood certification is "Chain of Custody" (COC) certification which provides credibility for certified wood products. COC is a system that allows the control of material sourcing and material tracking through transportation, storage, processing and distribution, ensuring that retailers and consumers are purchasing products that can be traced back to a certified source. This process also entails a system of audits of manufacturers and processors to confirm compliance and demonstrates that the entire process is tracked and verifiable. Providing COC Certification would be an important aspect of third-party certification protocol for the concrete and steel industries when establishing third-party certification.

What Can Be Learned from Wood Certification

It is clear that third-party certification of wood products has changed the wood industry. Some of the positives resulting from the creation, adoption and enforcement of third-party certification for the wood industry include the following:

- The wood industry has proactively created a more sustainable future for itself by carefully monitoring the world's forests.
- The public perception of wood has changed from a poor environmental choice to a sustainable one and therefore marketing of wood products has become easier.
- Certification of construction lumber products has helped to promote the popularity of other environmentally friendly forest-based products such as FSC certified paper products.

- The wood industry has created a market-driven process which provides the opportunity for sustainable lumber suppliers to differentiate themselves, and for consumers to make an informed decision about the sourcing of their materials.
- Indigenous peoples, local communities, and forestry workers are treated more fairly.
- Since third-party certification is independent, systems such as LEED have adopted these standards which have increased demand for these products.

Some aspects that may be considered negative include the following:

- There is an increase in the cost of materials to support the necessary change in practice and the documentation to confirm the material sources.
- A lack of incentives in some parts of the world may hinder adoption in these regions.
- Creation of new systems or continuing implementation of multiple existing systems is essentially unavoidable due to diversity of regions seeking certification.
- There has been some infighting among the competing certification systems.
- Consumers may become confused over too many certification options.

The success of third-party certification in the wood industry was largely as a result of increased public demand for more sustainable wood products. With the support of certified wood by companies such as Home Depot and by the LEED Certification system, certified wood became a more economically viable option. In order for the concrete and steel industries to be encouraged and successful in the creation of a third-party certification system the demand must be generated for more sustainable products. As members of steel and concrete industry organizations structural engineers can plan a key role in encouraging the development of sustainable materials certification systems.

Concrete

Concrete is one of the most widely used building materials in the world and its use is rapidly increasing particularly in developing countries. The production of Portland cement, the binder in modern concrete, is a highly energy-intensive process and results in significant CO₂ emissions. In 2010, approximately 3.6 billion tons of cement were produced worldwide, which is roughly double the worldwide production from the year 2000 (van Oss, 2010). Over half of the global cement production in 2010 came from China, where internal consumption is expected to increase more than 5% annually in the next several years. The rapidly increasing

global demand for cement use highlights the need for a reduction in the environmental impact of concrete.

In order to evaluate concrete properly as a material for certification, it is important to review all of the components that comprise concrete including cement, aggregates, and admixtures as well as the overall concrete mix designs and processes. Reviewing these materials and processes can identify areas where improvements can be made with the implementation of a third-party certification system.

Cement

Portland cement production is estimated to account for roughly 4% to 8% of total global CO₂ emissions. While some cement plants have improved their efficiencies and developed monitoring technologies over the past few decades, there are still areas for improvement.

Portland cement is comprised primarily of oxides of calcium, silicon, aluminum, and iron. The production process involves mining raw materials, reducing them with crushers at quarry plants, and transporting the crushed materials to the cement plant for refinement and proportioning. Typically limestone, shell, or chalk is combined with shale, clay, sand or iron ore. These materials are then heated in a kiln during which the materials undergo a process known as calcination where limestone decomposes into calcium oxide and carbon dioxide. Coal or natural gas is used to heat the materials to a temperature between 2500F and 3000F. At these high temperatures, the raw materials fuse to create clinker which is then transferred to coolers. Once the material is cooled, it is combined with gypsum and ground into a fine gray powder which is the finished Portland cement (cement.org). The two types of cement processes currently used are “dry” and “wet”. In the dry process, the materials are ground into a powder and fed into the kiln in a dry state, while in the wet process, water is added to the raw materials to produce a slurry.

The environmental impact of cement manufacturing can be measured by the amount of CO₂ released per ton of cement produced. On average globally, emissions in the calcination process account for 0.51 tons of CO₂ per ton of clinker, while 0.42 tons of CO₂ per ton of clinker are released in the fuel combustion process (Van Oss, 2005). This means that for every ton of cement produced roughly one ton of CO₂ is released into the environment.

In addition to the CO₂ released in the production of cement, the energy required in the production process must also be assessed. Roughly two-thirds of the energy used in cement production comes from coal, with a little under a quarter from petroleum coke (energystar.gov). The energy required for cement manufacturing varies largely based on the efficiency

of the plant and the production process used (wet, long dry, dry with preheater, or dry with preheater and precalciner). In the past few decades, the improvements made by the concrete industry have been largely due to an increased investment in the dry process of cement manufacturing while phasing out plants relying on the more energy-intensive wet process. Currently 85% of U.S. plants utilize the dry process (cement.org/econ). Advancements in the kiln system such as the invention of preheaters and precalciners have also improved efficiencies. The most efficient cement production process is use of a preheater with a precalciner, followed by preheater without precalciner, long dry kilns, and wet kilns. Long dry kilns consume roughly 33% more thermal energy and wet kilns about 85% more than preheater with precalciner (wbcsdcement.org).

Reductions in cement production emissions can also be achieved through clinker substitution with materials having significantly lower associated emissions, such as post-industrial waste products. Slag, fly ash, and volcanic materials are examples of clinker substitutions in cement production since they also contain some or all of the primary chemical constituents found in clinker. Ordinary Portland cement can typically have up to 5% clinker substitution, but the percentage depends on regional standards. Cement with larger substitution percentages is referred to as “Portland composite cement”. Clinker substitution reduces the volume of clinker required in cement and therefore the associated energy emissions resulting from clinker production (wbcsdcement.org). Europe generally allows for a higher level of clinker substitution thus reducing their carbon impact per ton of cement produced. An example of this is Portland-limestone cement (PLC) which is making its way onto the market in Canada and Europe. PLC is manufactured by grinding Portland cement clinker with limestone. In PLC, up to 15% of the clinker used to produce regular Portland cement is replaced by limestone. This and other advances are important in reducing the carbon footprint per cubic yard of concrete as cement is by far the greatest contributor to the carbon footprint of concrete, as evident in Table 1.

Table 1: Concrete Fuel Consumption per Yard

Material	MBtu/yd3	% of Total
Cement Manufacture	0.622	87%
Aggregate production	0.021	3%
Transportation	0.054	7%
Plant Operations	0.020	3%

In addition to CO₂ and energy input, a large amount of water is required to produce cement, with the amount varying by production method. Water used in cement production can be classified as “process water”, which is used to create raw meal slurry in the wet process, or “non-process water”, used

for cooling and dust suppression. Only the wet process uses a significant amount of process water, with the long dry process using the least amount of water overall (See Table 2). (Marceau, 2007). By reducing the amount of water required for producing, treating and managing the cement production manufacturers can decrease the environmental impacts of the cement plants and the required energy to treat the post-process water.

Table 2: Water Usage per Cement Process Type

Production Method	Process Water (lb/ton)	Non-Process Water (lb/ton)	Total Water Use (lb/ton)
Wet	969	1148	2117
Long Dry	0	2266	2266
Precalciner	28	1183	1211
Preheater	14	2267	2281

Human health is also a concern in cement production. Mercury runoff from cement plants can be deposited into waterways where it is absorbed by fish. Human exposure to methylmercury before birth or at a young age can affect neurological development. Additional health concerns can arise when cement kiln dust (CKD), a byproduct of cement manufacturing, is sold as an agricultural liming agent since the CKD can end up in water supplies or food products. Use of CKD in unpaved roads can also result in water contamination (epa.gov).

Aggregates & Sands

Aggregates and sands comprise the majority of the volume of concrete. Aggregate extraction methods vary based on the location of the concrete mix plants, but are typically mined from quarries or sourced from rivers. Irresponsible strip mining can cause damage to the environment and can result in harmful particulates in water run-off as well as have detrimental effects on local populations, wildlife, and the ecosystem. There is currently no means for structural engineers to request that the specified aggregates and sands were obtained in an environmentally friendly way. This type of specification would be one component of third-party certification for concrete materials.

There are examples of sustainable methods currently being practiced by some suppliers of aggregates and sands. However, these methods are not currently recognized. One example of a sustainable approach to river aggregate extraction is to source the materials from the downstream side of a gravel bar. This method of extraction allows the upstream portion of the gravel bars to remain intact and minimizes disruption to the ecosystem. This prevents disruption to the river flow and preserves the gravel bar. When river levels rise in the winter months, the mined bars

are filled in with sediment and rock washed down from upstream creating a closed-loop cycle. This type of sustainable extraction method could be recognized by a third-party certification system and encourage other suppliers to practice more sustainable extraction methods.

Concrete Admixtures

Concrete admixtures such as superplasticizers and shrinkage-reducers are often used to aid in the placing and curing of concrete. Admixtures can contribute to the durability of concrete and have become an important and beneficial part of the concrete industry. Admixtures are composed of both organic and synthetic chemicals. In studies on the environmental impacts of admixtures it was found that in general admixtures have a very small effect on the total environmental impact of concrete. However, the production of admixtures can have a negative impact on the environment due to the chemical waste released during the production of superplasticizer (admixture.org.uk). Similar to the choices available for structural steel primer and other chemical products, structural engineers would be able to specify more environmentally friendly admixtures that can meet the required performance specifications. However, there is currently no way to differentiate between the environmental impact of various admixture manufacturers. Third-party certification of admixtures along with the rest of the concrete elements could address this and provide the necessary information.

Concrete Mix Plants

In concrete mix plants, all of the concrete ingredients are combined in specified proportions. “Ready mix plants” and “central mix plants” are the two types of production methods currently used. A ready mix plant combines all the ingredients except water at the plant. The mix is then loaded into a truck where water is added while the mix is transported to the jobsite. A central mix plant combines all of the mix ingredients, including water, at the plant. This type of process offers a more uniform output, since all the mixing is done at one location. A mix plant’s efficiency depends on the type of equipment used and the organization of the plant’s operations. The EPA’s ENERGY STAR program and the National Ready Mixed Concrete Association (NRMCA) have programs in place focusing on improving the energy efficiency in ready mix plants. Concrete mix plants in the U.S. are regulated by the Concrete Plant Manufacturers Bureau, which establishes minimum standards as well as ensuring quality control at the plants.

Reducing the amount of cement used in concrete is clearly one of the most important things that can be done to reduce concrete’s environmental impact. Two of the most direct

strategies to reduce cement include using supplementary cementitious materials and providing more careful monitoring and quality control of the amount of cement used in mixes to reduce excess cement in concrete mixes.

Supplementary cementitious materials commonly specified by structural engineers and used in concrete include fly ash, a waste byproduct from coal burning electric power plants, ground granulated blast-furnace slag (GGBS), a byproduct of iron and steel manufacturing; and silica fume, a waste byproduct from the manufacture of silicon or ferro-silicon metal. These materials, which would normally be deposited in landfills, can replace a significant portion of the cement needed in a concrete mix and greatly reduce the environmental impact per yard of concrete (nrmca.org).

In addition to the use of supplementary cementitious materials, providing better quality control and monitoring systems for cement mix plants can help to reduce cement use and uncertainty in mix designs. Due to inadequate quality control, plants will often use extra cement to offset the risk of concrete not achieving the specified strength. Also, concrete trucks may be rejected at the project site by the inspectors because the mix does not properly conform to the specifications, resulting in concrete that is not usable. Developing better quality control procedures at mix plants could reduce the amounts of cement used per yard of concrete. Third-party certification of concrete mix plants would provide structural engineers with the ability to specify concrete from more efficient suppliers.

Some methods for plants to decrease the amount of cement already exist in the marketplace. For example, a California-based company called iCrete has developed a proprietary procedure for designing concrete mixes that it they claim can reduce Portland cement content in mixes by between 10% and 40% without using any special admixtures and without compromising strength. They also note that extra cement usually increases early strength gain but can compromise long-term durability and cause other problems. The iCrete technology can be licensed by existing concrete mix plants.

Presumably there is a cost premium for concrete mix plants to improve their quality control plans. Without any real demand or a way to recoup added costs, there is no incentive for plants to make these types of improvements. Third-party certification of concrete would allow structural engineers to specify the use of plants that reduce cement, creating the demand needed for plants willing to change their practices.

Concrete Industry Organizations

In the U.S., the concrete industry is currently supported by two main organizations focusing on the use and benefits of

concrete—the Portland Cement Association (PCA) and the NRMCA. Outside of the industry the U.S. EPA and the Cement Sustainable Initiative (CSI) have both set environmental standards which impact concrete production.

The PCA represents cement manufacturers in the United States and Canada with a primary focus on research, education, engineering, market development and public programs. To keep up with the trends and popularity of sustainability, the PCA has concentrated part of its efforts on promoting the sustainable benefits of concrete through the development of the Cement Manufacturing Sustainability (CMS) Program. The focus of the program is to “balance society’s need for cement products with stewardship of the air, land, and water, conservation of energy and natural resources, and maintenance of safe work places and communities.” (cement.org) The program is based on a voluntary code of conduct revolving around a set of principles set forth by the PCA Board of Directors in 1991. These measures set goals for the year 2020 to achieve a 10% reduction in CO₂ from the 1990 baseline as well as reduce cement kiln dust and energy use. PCA has established a goal to increase the number of plants with an in-place Environmental Management System aimed at establishing processes and practices to achieve environmental targets.

The NRMCA focuses on ready mixed concrete and has implemented a variety of programs since its inception. One such program is the NRMCA “Checklist for Ready Mixed Concrete Production Facilities” which was created to address numerous concrete failures which occurred in the early 1960’s. This checklist later evolved into the “Plant Certification Program”. Achieving “Plant Certification” assures that the concrete from certified plants meets or exceeds standard quality control requirements from ASTM or AASHTO. Like PCA, NRMCA recently set sustainability goals with the development of the NRMCA Sustainability Initiatives. The Green-Star Certification Program and the Sustainable Concrete Plant Guidelines have both developed out of these initiatives. The Green-Star system operates by plants setting their own internal environmental goals which are monitored biannually by certified auditors. The Sustainable Concrete Plant Guidelines determine the environmental effects of a plant based on its embodied energy and carbon footprint and award it a Bronze, Silver, Gold or Platinum rating. This type of rating system could become one element of a third-party certification system of concrete.

How the Concrete Industry is Currently Regulated

Currently the EPA regulates the concrete industry by setting emission standards for cement manufacturing. Cement plants report their production statistics, such as clinker produced,

kiln capacities, and amount of fuel used in production annually. Despite the availability of these statistics, there is no way to recognize efficient plants and no requirement for less efficient plants to improve. In 2010 the EPA set rules for significant reductions of mercury and other toxin levels.

The CSI is a project of the World Business Council for Sustainable Development which is a global effort by eighteen major cement producers in over 100 different countries with a goal of reducing CO₂ emissions from cement production. These member companies account for 30% of the world’s cement production. The CSI has set targets for up to 25% reduction in CO₂ from a 1990 baseline by 2015 (wbcsdcement.org). With the monitoring programs and governing bodies currently in place a standardized third-party certification system could be developed to apply to all environmental aspects of the industry.

Opportunity for the Concrete Industry to Change

It is clear there are many opportunities for the concrete industry to reduce its impact on the environment. Some of the opportunities include the following:

- Reducing the amount of pollutants and carbon dioxide given off during cement production compared to a baseline.
- Reducing the amount of energy used to make cement compared to a baseline, which may also result in reduced production costs.
- Exploring the idea of “co-generation” to recapture and use some of the energy used in cement production.
- Using renewable energy sources for cement making, concrete mixing, and transportation.
- Ensuring that responsible mining practices and fair treatment of local populations and wildlife are used when collecting limestone and other raw materials used as inputs for cement production, and also when mining aggregates and sand for use in concrete.
- Encouraging the development of chemical admixtures that are less harmful to the environment.
- Reducing the amount of cement used in concrete mixes by promoting less energy-intensive replacements such as fly ash, slag, and silica fume.
- Reducing the amount of cement used in concrete by using more careful monitoring procedures as the concrete is mixed, which may also improve overall quality control of the concrete.
- Taking strength test cylinders or reviewing the owner’s testing laboratory reports to establish the optimal amount of cement required to achieve the specified strength, thereby reducing the amount of cement used.

By addressing the opportunities noted above, the concrete industry can greatly improve its global image and improve the marketing of its products. Third-party certification would give structural engineers the ability to specify more environmentally friendly choices which would create a demand for the concrete producers and material suppliers to change current production and delivery methods. Considering concrete is one of the most widely used building materials, and consequently is the largest global CO₂ emitter among building materials and is the third largest emitter of all human industrial processes, sustainable material certification for this industry is essential in reducing the environmental impact of buildings.

How This Could be Achieved

While the concrete industry has continued to make improvements, a third-party certification system would enable consumers to purchase concrete from more efficient and environmentally-friendly plants. In order to provide certification for the concrete industry, all components of a concrete mix must be assessed including cement, aggregates and sands, admixtures and the concrete mix plants.

Of the components required in concrete certification, cement has the largest impact on the carbon footprint of concrete. Of the carbon emissions generated by cement, roughly 60% of these emissions come from the chemical decomposition of limestone (wbcsdcement.org). This means that even the most efficient cement plant can only effect the carbon emissions of the remaining 40%. Therefore, it is important to continue to utilize cement replacements such as fly ash and slag and to continue to research other cement substitutes.

Achieving a certification system for the cement industry would be a two-part process. First, there needs to be a way to classify and monitor the efficiency of existing cement plants. Second, there needs to be a system in place for less efficient plants to improve. The foundations for these processes already exist but require the support of the industry.

There are two standards for calculating and reporting CO₂ emissions associated with the manufacturing of cement: the California Climate Action Registry and CSI's Cement CO₂ Protocol. Both protocols are designed to provide instructions on calculating and reporting CO₂ emissions associated with manufacturing cement (arb.ca.gov). There is also an Energy Performance Indicator (EPI) developed by the EPA that enables the comparison of the energy efficiency of a specific U.S. based cement manufacturing plant to that of the industry within the U.S. The EPI produces a plant percentile score between 1 and 100 and compares that score to the most energy-efficient and average plants in the industry and to previous performance for the plant. The data required to

produce a score includes annual energy use by fuel type for the most current year, annual energy use by fuel for baseline year, plant location, daily plant capacity of clinker production, total amount and type of products produced, and energy consumption data (electricity, gas, oil, coal). This information could be developed into baseline levels and used to determine recommended levels for achieving certification.

There have been numerous studies on how cement plants can improve their efficiencies. In a study released by the Environmental Defense Fund (EDF) it was estimated that improvements in cement plants could result in up to a 65% savings in energy costs. Lawrence Berkeley National Laboratory researched the possibility of implementing some of these measures through case studies of cement plants in California. In the case study cement plant managers were interviewed about undertaking energy efficient investments at their plants. They stated factors key to their business were environmental regulations, market conditions, and energy costs. Keys to their company's success were identified as, most importantly, meeting regulatory requirements and meeting production schedule. Energy savings was not seen as very important to their success mainly due to limited capital, production concerns, limited staff time, information, reliability concerns, hassle, and facility uncertainty. Despite energy costs being recognized as the largest variable in the production costs at concrete mix plants, none of the recommended energy efficiency programs were implemented. This was reportedly due to a short program period, limited incentives, measurement and verification requirements, and program paperwork (ies.lbl.gov). The introduction of a third-party certification system would recognize more efficient plants and provide incentives for less efficient plants to invest in energy saving technologies.

Impact of Upgrading to the Industry

Certification will allow the U.S. concrete industry to demonstrate its commitment to producing a more sustainable building material. While upgrading of systems and changing practices will come at an initial cost premium to the industry there is potential for cost savings due to these upgrades. Based on the Environmental Defense Fund study, the cement industry is a \$9 billion industry, spending \$1.7 billion on energy. With the proposed EDF upgrades, which include improvements to raw material preparation, clinker making, finish grinding, plant efficiencies and product changes, the cement industry stands to decrease their energy costs by \$1.1 billion. Most of these technologies have estimated payback periods of 5 years or less (edf.org). The International Organization for Standardization already has management framework standards that plants can follow that have documented success in improving energy efficiency. While such upgrades may have initial financial and production level

impacts, the industry will benefit from decreased energy costs and increased marketing with competitors.

Next Steps for Achieving Concrete Certification

As stated in the introduction to this section, the use of concrete is rapidly increasing on a global level. Therefore, it becomes even more imperative that actions are taken to reduce the environmental impact of the materials that are being used in building construction. While structural engineers are not directly involved in the development of concrete production, by encouraging and specifying the use of certified concrete materials engineers can help generate a demand for these types of materials. As shown in the development of the wood industry, creating a demand for these types of products will generate greater action by the industries involved and move the certification process forward.

Steel

Steel is a largely recycled material with over 40% of steel production being consumed by the construction market (steel.org). While the concept of steel as a recycled material is often used to promote steel as a “green” material, the manufacturing of steel is a highly energy intensive process that has impacts on the environment. Additionally, the production of steel results in byproducts that are harmful to the environment. While general manufacturing has greatly improved in efficiency since the early 1900’s, many aspects of the steel industry production process have remained relatively unchanged due to abundant resources. However, as resources become scarce and the human impact on the environment is more acutely felt, it is important to review traditional processes. By establishing a third-party certification system to encourage the industry to improve its efficiency and creating greener alternatives, designers can provide a demand for a more sustainable material. By understanding the sourcing, manufacturing, and current regulations of the steel industry, areas can be identified where the industry can improve and reduce its environmental impact.

History of the Steel Industry

The original steel manufacturing process utilized a blast furnace with charcoal as its fuel source due to the local and abundant sources of charcoal in steel manufacturing regions. Due to diminishing resources, by the turn of the nineteenth century, iron producers were forced to use alternative fuels in the form of bituminous coal, anthracite coal, and coke.

While the U.S. has one of the lowest energy consumption and CO₂ emissions per ton of steel produced, steel production still

accounts for 6% of U.S. energy consumption (Stubbles, 2011). Due to advancements in technology such as the replacement of the open hearth process with basic oxygen and electric furnaces, the U.S. has achieved a 30% reduction in the energy required to produce one ton of steel, as shown in Figure 1, and greenhouse gas emissions have decreased by 35% since 1990 (steel.org). However, advances have begun to level off in recent years while material demand continues to increase.

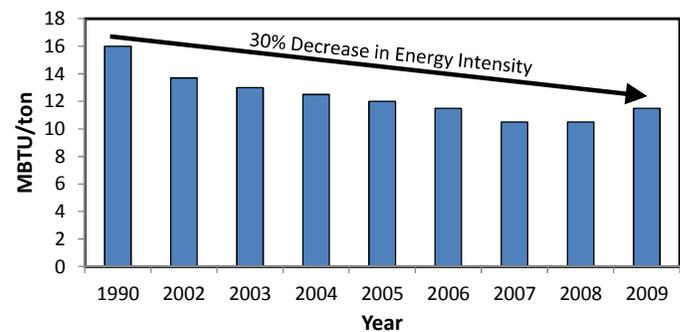


Figure 1: Energy Intensity of Steel Production Over the Past 20 Years (steel.org)

Mining and Processing of Coal & Iron Ore

The mining of coal and iron ore is necessary in the production of steel in either the basic oxygen furnace (BOF) or electric arc furnace (EAF) facilities. Coal and iron ore are mined through either open pit mining (i.e. strip or contour mining) or underground mining. Open pit mining involves the removal of soil until the coal or iron ore is exposed, disrupting the surrounding ecosystem. Underground mining involves the drilling of a vertical shaft to the coal or iron ore with horizontal shafts radiating from this point and is less impactful on the environment. Open pit mining is the preferred method of the steel industry as it is generally more economically attractive. (Fruehan, 1998)

Iron does not occur in nature as a readily usable metal and it must be processed prior to fabrication of iron products. Iron ores are chemically united with several elements including oxygen, manganese, and phosphorus. The beneficiation and agglomeration process of the ore involves the removal of unwanted elements and the control of wanted ones thereby improving the raw material. This results in waste material and the process of creating the steel-ready iron requires large amounts of energy input (Fruehan, 1998).

Human Impact of Mining

Mining poses a potential environmental hazard to humans, as coal and iron ore mining activities can pollute local water supplies (e.g. “acid mine drainage”), cause noise and air pollution, lead to erosion, and impact local biodiversity. While the current U.S. EPA regulations have limited the impact of mining activities on local communities, there are over 200,000 inactive and abandoned mines that continue to cause environmental problems (epa.gov). Reclaiming the land used by these inactive mines in order to mitigate environmental hazards is a slow and expensive process.

Current Steel Production Practices

Market pressures driving change are not unique to the steel industry as many other US based industries have been forced to adapt to modern environmental standards. Starting in the late twentieth century, the industry faced a difficult challenge in meeting new government mandates regarding environmental responsibility. During this same period the industry saw significant consolidation of manufacturing facilities including a reduction in its workforce. Today, domestic competition has been overshadowed by increasing international competition in a global economy.

Currently, steel is manufactured at either an “integrated mill” through the BOF process or a “mini mill” in an EAF. Both manufacturing processes involve the removal of carbon through oxidation forming carbon monoxide. In a BOF, the process occurs when oxygen is introduced to hot metal produced in a blast furnace. In an EAF, the process occurs from melting and refining scrap as well as other forms of iron. After the steel is treated in either the BOF or EAF a secondary process of deoxidation, desulfurization and vacuum degassing occurs. (Fruehan, 1998) Currently BOF production accounts for approximately 40% of total steel production with EAFs producing the majority of the remaining steel (steel.org). The BOF process uses 25-35% of scrap steel in the production of new steel while EAFs typically use over 90% of scrap steel in the production of new steel. Additionally, EAF facilities consume approximately one-third the energy compared to BOF facilities (steelnet.org). It should be noted that if scrap material becomes less available, more virgin material will be required for steel production regardless of the process used.

Steel Industry Organizations

Several professional and trade organizations represent various parties associated with the steel industry with the main focus of promoting and representing the U.S. steel and mining industry. Some of the main organizations include American Iron and Steel Institute (AISI), Steel Manufacturers Association (SMA), American Institute of Steel Construction

(AISC), World Steel Association (WSA) and the National Mining Association (NMA). AISI focuses on the statistics of the steel industry and setting industry standards. SMA represents the majority of the EAF steelmakers in North America with a focus on the domestic environmental costs in the global market as well as a focus on safety, plant operations, the environment, human resources, and transportation. AISC represents producers, fabricators, detailers, erectors and designers as well as performing certification of manufacturing plants addressing quality control and best practices. WSA represents 85% of the steel producers in the world. In the early 1990’s WSA released a sustainable development policy and the first steel industry life cycle inventory was published to ISO standards. Additionally, in the early 2000’s a climate change policy was agreed upon. The industry trade groups described above could be a source for encouraging the adoption or providing a framework for third-party certification.

How the Steel Industry is Currently Regulated

In the U.S., the environmental impact of the steel industry is currently regulated by federal and state laws such as the Clean Air Act (CAA), Clean Water Act, and Resource Conservation and Recovery Act. These laws define limits on air and water pollutants, and regulate the generation, use, and disposal of hazardous wastes. In 2011, under the CAA, the EPA began a phased process to regulate greenhouse gas (GHG) emissions from industrial sources. The regulations apply to new large plants or large-scale upgrades to existing plants. These projects will be required to employ “best available control technology” to curb the emission of GHGs such as CO₂, methane, and hydrofluorocarbons. Smaller plants will not be subject to the new ruling until at least 2013 (epa.gov). While these regulations are in place, there appears to be no numerical target values, only the requirement of using “best available control technology”.

Currently there are no laws which regulate the energy efficiency of the steel industry. Because steelmaking is energy-intensive, improving energy efficiency has the potential to result in significant reductions in the industry’s GHG emissions. The steel industry has developed voluntary energy reduction initiatives in cooperation with the U.S. Department of Energy (DOE) and the EPA. The EPA’s Energy Star Program and the DOE’s Industrial Technology Program have led industry specific energy efficiency initiatives over the years. These programs have helped to create guidebooks of energy efficient technologies, profiles of industry energy use, and studies of future technologies. Some states have also led sector-specific energy efficiency initiatives. Resources from these programs can help to identify technologies that may reduce CO₂ emissions.

Opportunities for the Steel Industry to Change

Past reductions in carbon emissions were largely due to two factors: the switch from open hearth furnaces to blast oxygen furnaces and the increased use of EAFs due to increased availability of scrap and technical developments. With increasing demand for steel it is important to look for new avenues to decrease environmental impacts. In addition to energy usage and its resulting CO₂ emissions, the steel industry produces other air emissions including nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon oxides (CO), and volatile organic compounds (VOCs), as well as water emissions and solid wastes. While each step of the steel making process has some associated environmental impact, the main areas with pollution prevention opportunities are cokemaking, EAF dust, and finishing acids.

Coke production is perhaps the area of greatest environmental concern in the steel making process, with coke oven emissions and quenching water being the greatest contributors. Coke oven emissions are comprised of several hazardous wastes, including tar residues, oil, naphthalene residues, and lime sludge, and has been classified by the EPA as a known carcinogen (epa.gov). Water quenching uses large quantities of fresh water and contaminates that water with coke breezes and other compounds. One of the most effective ways to reduce the negative air and water impacts associated with cokemaking is to use less coke during the ironmaking process. For example, pulverized coal and other fossil fuels can substitute a portion of the coke required during ironmaking. Cokeless technologies, which substitute coal for coke in the blast furnace requires significant capital investment, but has enormous potential to reduce pollution during the steel making process (EPA, 1995). Dry quenching technology can mitigate many of the problems associated with conventional wet quenching and has been used in Europe and Asia.

The growth in EAF-produced steel has resulted in a corresponding growth in the production of EAF dust. EAF dust is classified by the EPA as a hazardous waste because of its high concentrations of lead and cadmium, the source of which is the scrap metal used in EAF production (i.e. scrap steel with lead-based paint). Steel producers can either landfill EAF dust or sell it to recyclers who can recover the zinc within the EAF dust.

Lastly, finishing processes clean the surface of semi-finished steel prior to cold-rolling, forming, or coating processes. Acid pickling, a common finishing process, involves immersing steel into a tank of hydrochloric or sulfuric acid. The resulting spent pickling acid is classified by the EPA as a hazardous waste. While disposal of the spent acid is an option, there are various alternatives. For example, there is

equipment currently available which can recover the hydrochloric or sulfuric acid for reuse with the only by-products being water, which can be reused, and iron chloride, which can potentially be sold.

The steel industry also uses large quantities of fresh water for quenching and rinsing throughout the steel making process. It is estimated that 75,000 gallons of water is used per ton of steel produced (ncms.org). The replacement of single-pass wastewater systems with closed-loop systems, along with the utilization of technologies such as dry quenching, can significantly reduce water usage.

In addition to looking at the efficiencies of steel mills it is also important to review the energy efficiencies of the structural steel fabricators. In the July 2010 edition of *Modern Steel Construction* (MSC), AISC's Director of Industry Sustainability Geoff Weisenberger points out that steel fabricators can play a tremendous role in reducing the environmental impact of steel. The article reported on a survey conducted for AISC by a third party engineering and environmental consulting group. While the numbers reported in MSC are preliminary, it was determined that the average steel fabricator contributes approximately 20% to the structural steel packages portion of a steel buildings overall environmental impact. Approximately 70% to 80% of the environmental impact is due to the electrical usage by the fabricators, with natural gas and diesel fuels being the next largest contributors. Therefore by reducing the fabricators dependence on energy, through the use of solar and other forms of sustainable energy, the fabricators environmental impact can be greatly reduced.

How This Could be Achieved

Currently the average amount of energy used to produce one ton of steel is 9.0 and 18.1 MMBtu/ton for the EAF and BOF processes respectively (See Table 3) (DOE, 2011). The SMA estimates that a ton of steel produced using the EAF and BOF processes emit 0.74 and 1.91 tons of CO₂ respectively (steelnet.org). Fabrication processes emit an additional 0.19 to 0.26 tons of CO₂ per ton of steel (Weisenberger, 2010).

By using the energy efficiency technology currently available, as discussed by the U.S. Department of Energy (DOE), the energy required in steel production can be reduced by up to 2.76 MMBtu/ton of steel produced (See Table 4). This level of reduction equates to a 31% reduction and 15% reduction for the EAF and BOF processes respectively.

While the DOE notes that these upgrades are technically available they may not be economically viable in all situations.

Table 3: Comparison of Energy Use for Steel Production Processes in MMBtu/ton (DOE, 2011)

	Agglomeration	Cokemaking	Steelmaking	Reheating/ Hot Rolling	Total	Source
World Average Basic Oxygen Furnace (BOF)	3.0	2.0	13.0	3.0	21.0	International Energy Agency, 2007
U.S. BOF 2010 (Forecasted)*	16.0			2.1	18.1	Steel Bandwidth Study, 2004
U.S. Electric Arc Furnace (EAF) 2010 (Forecasted)*	N/A	N/A	7.0	2.0	9.0	Steel Bandwidth Study, 2004

Table 4: Potential Energy Reductions for Steel Production

Method of Reduction	MMBtu/ton Savings
Preventive Matintenance	0.21
Installation of energy monitoring devices	0.06
Coal moisture control in cokemaking process	0.22
Coal and natural gas injection, recovery turbines, hot-blast stove automation, and systems for improved blast furnace control	1.34
Casting/hot rolling energy efficiency	0.93
Total Savings	2.76

Impact on the Steel Industry

Third-party certification will allow the U.S. steel industry to demonstrate its commitment to producing green and sustainable products and directly market this commitment to its consumers. In order to achieve certification of their products, the steel industry may need to change their operational and business practices and make potentially large capital investments. Manufacturers that are already operating at a high level of efficiency, both in terms of energy usage and air/water emissions will require less change and capital investment than those further from the certification requirements. Certification will also require the steel industry to operate with greater transparency by publicly reporting their energy usage and carbon emissions data. A key to reducing carbon emissions is better understanding of actual emissions from steel plants for various production

processes. This will allow the steel industry and individual plants to identify realistic emissions reduction targets.

The production of greener products often comes at a high initial price. A reduction in air and water emissions often requires the installation of scrubbers or other pollution control equipment. This requires capital to purchase the equipment, downtime to install it, and possible retrofit to existing equipment and systems as well as investing in newer technologies. There are also costs associated with training workers on how to operate the new equipment and the resulting temporary loss in productivity. In the long run some of these upfront costs may be offset by savings in energy costs.

Perhaps the biggest advantage of steel certification is that it would provide manufacturers with the opportunity to differentiate themselves from their competitors. Steel is a commodity which is bought and sold on the international market and domestic steel producers are dealing with increasing competition from international markets. In the building industry the physical properties of steel are standardized, meaning cost and schedule are the main factors in determining from whom steel is purchased. While currently there are often requirements that structural steel be comprised of a certain percentage of recycled content, the vast majority of steel already meets this requirement due to the high usage of scrap.

Currently, if a steel producer makes investments to increase the sustainability of their products they have no means of relaying this information to their customers. Certification would allow producers to be recognized for their commitment to sustainable practices and allow them to price their product in a manner which reflects the increased cost of implementing green practices. Producers of certified steel would also be able to tap into the growing consumer demand for green products.

Next Steps for Achieving Steel Certification

The certification program for steel will ideally be implemented voluntarily through existing industry trade organizations such as AISI, AISC or WSA. Both AISC and AISI have systems in place which monitor efficiencies within their member plants. Most of these systems help monitor for business efficiencies yet the fact that they are in place means they could be expanded to incorporate an agreed upon set of sustainable guidelines. The International Iron and Steel Industry (IISI) has already published guidelines that suggest criteria that the industry could follow. The IISI would be a very well positioned organization to incorporate sustainable guidelines and principals both in the United States as well as the global steel community. Industry support is also key in

the development of breakthrough technologies required for significant future reductions in energy usage and carbon emissions, for example through sponsorship of Research and Development being conducted at colleges and universities.

Currently structural engineers have the ability to specify steel with a high recycled content. However, the availability of scrap material typically determines the recycled content of steel and is therefore largely outside of the engineer's control. Therefore it is important to review those elements which can be improved upon, including the energy required in steel production and the associated emissions. It is important that structural engineers become advocates from within the steel organizations to provide certified steel materials and specify these types of materials when they become available.

Conclusion

With buildings accounting for nearly a third of the impact on the environment in the U.S. and around the world, there is a clear need to address the environmental impacts of construction materials. Structural engineers can play a large role in reducing the environmental impact of building materials provided the appropriate tools are available. Currently, wood is the only structural material that has a procedure in place to differentiate between sustainably sourced materials. An engineer designing a wood-framed structure can specify third-party certified lumber such as FSC or SFI, but cannot do the same for concrete and steel structures. The lack of an independent third-party certification system for concrete and steel severely limits the impact structural engineers can have on reducing negative environmental effects.

Sustainable material certification for concrete and steel will provide an opportunity for individual providers, mills, plants, and fabricators to distinguish themselves as leaders of the industry in sustainability. At the same time, it provides a pathway for green building specifiers to ensure best practices are being used in the extraction, production, and fabrication of their project's materials. Given the relatively low embodied energy of wood compared with the other building materials, there is even greater potential for reducing the environmental impact of construction materials through similar certification processes for concrete and steel.

The envisioned independent third-party certification systems would be adopted and maintained voluntarily. This permits the market to drive the adoption of these standards. As has been shown in the wood industry, LEED and other green building codes can adopt and encourage these systems, creating a demand and have a large impact on the industry while advancing environmental stewardship goals. Dovetail Partners, an environmental research group, released a paper

entitled "USGBC Forest Certification Benchmarks: An Opportunity for Development of Certification Standards for all Building Materials", which illustrates how the certification standards of the wood industry could be applied to the concrete and steel industry. This paper provides an example of how such a certification system could be developed and would be a good starting point in the development of steel and concrete certification.

LEED certification currently looks only at the recycled content of steel and concrete, but its recognition of FSC-certified lumber indicates that this requirement may change to require the use of certified steel once it becomes available, thereby spurring the demand for certified steel. The USGBC anticipates a 75% increase in LEED-certified square footage over the next four years in response to growing consumer demand (McQuilken, 2011). Federal agencies and state and local governments are beginning to mandate LEED certification of projects fully or partially funded by public monies and encourage its use on private projects by offering incentives such as tax credits and fast-track permitting. While third-party certification would require changes to be made in the steel and concrete industry, the benefits both to the environment and the industry itself could largely outweigh the costs.

As professional engineers, we should continually strive to hold ourselves to the highest ethical standards. In the ASCE Code of Ethics, the first 'Fundamental Canon' states that "Engineers shall hold paramount the safety, health, and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties" (ASCE Code of Ethics, App. A). It goes on to define sustainable development as balancing the industry needs with the conservation and protection of environmental quality and the natural resources which are necessary to future development. If structural engineers are going to contribute to the continuing call to make the built environment more sustainable, then setting higher goals for the materials structural engineers specify must be achieved.

References

Air Resources Board. California Environmental Protection Agency. Web. 30 May 2011. <http://www.arb.ca.gov>

American Iron and Steel Institute. Web. 30 May 2011. <http://www.steel.org>

Bell, Jeff. "Concrete Energy Savings - On-Site Power For the World's Cement Industry". *Cogeneration & On-Site Power Production*. 1 May 2007.

Bowyer, Dr. Jim, Dr. Jeff Howe, Kathryn Fernholz and Dr. Steve Bratkovich. "USGBC Forest Certification Benchmarks: An Opportunity for Development of Certification Standards for all Building Materials". *Dovetail Partners*. October 28, 2009.

Cement Sustainability Initiative. World Business Council for Sustainable Development. Web. 30 May 2011. <<http://www.wbcscement.org>>

CAA – UK Cement Admixtures Association. Web. 30 May 2011. <<http://www.admixture.org.uk>>

"Coke Oven Emissions". U.S. Environmental Protection Agency. January 2000. Web. 30 May 2011. <<http://www.epa.gov/ttnatw01/hlthef/cokeoven.html>>

Dransfield, J M. "Leaching of Admixtures From Concrete". UK Cement Admixture Association and the European Federation of Concrete Admixture Associations.

Energy Flow Charts. Lawrence Livermore National Laboratory. Web. 30 May 2011. <http://www.llnl.gov>

Energy Star. U.S. Environmental Protection Agency. Web. 30 May 2011. <<http://www.energystar.gov>>

Entine, Jon and Moon Doh. "NGO's Battle Over "Green Wood" Certification". *Global Governance Watch*. 29 Sept. 2009. Web. 30 May 2011.

Environmental Defense Fund. Web. 30 May 2011. <http://www.edf.org/home>

Fernholz, Kathryn, Dr. Jeff Howe, Phil Guillery, and Dr. Jim Bowyer. "Beginner's Guide to Third-Party Forest Certification: Shining a Light on the Endorsement of Forest Certification Schemes (PEFC)". *Dovetail Partners*. Nov 19, 2004.

Fernholz, Kathryn, Dr. Jeff Howe, Dr. Steve Bratkovich, and Dr. Jim Bowyer. "Forest Certification: A Status Report". *Dovetail partners*. March 23, 2010.

"Final Rule: Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule". U.S. Environmental Protection Agency. Web. 30 May 2011.

The Forest Stewardship Council. Web. 30 May 2011. <<http://www.fsc.org>>

Fruehan, Richard J. The Making, Shaping and Treating of Steel. American Society of Metals, The AISE Steel Foundation. 1998.

Guillery, Phil, Dr. Jeff Howe, Kathryn Fernholz, and Dr. Jim Bowyer. "Beginner's Guide to Third-Party Forest Certification: Shining a Light on the Forest Stewardship Council (FSC) Approach". *Dovetail Partners*. Sept 15, 2004.

Guillery, Phil, Dr. Jeff Howe, Kathryn Fernholz, and Dr. Jim Bowyer. "Beginner's Guide to Third-Party Forest Certification: Shining a Light on the Sustainable Forestry Initiative (SFI)". *Dovetail Partners*. Oct 20, 2004.

Hansen, E., R. Fletcher, B. Cashore and C. McDermott. "Forest Certification in North America". *Oregon State University Extension Service EC 1518*. January 2006.

Howe, Dr. Jeff, Dr. Jim L. Bowyer, Phil Guillery, Kathryn Fernholz. "Chain-of-Custody Certification: What Is It, Why Do It, and How?". *Dovetail Partners*. May 20, 2005.

International Energy Studies. Lawrence Berkeley National Labs. Web. 30 May 2011. <<http://ies.lbl.gov>>

"Iron & Steel, Impacts, Risks and Regulations." *National Center for Manufacturing Sciences*. n.p. 10 August 2004. Web. 15 May 2011.

MacDonald, Christine. "FSC vs. SFI". *ArchitectureWeek*. 12 August 2009. Web. 30 May 2011.

Malhortra, V.M. and P.K. Mehta. High-Performance, High Volume Fly Ash Concrete for Sustainable and Durable Structures. Supplementary Cementing Materials for Sustainable Development Inc. Ottawa, Canada. 2008.

Marceau, M., M. Nisbet, and M. VanGeem. "Life Cycle Inventory of Portland Cement Concrete". Portland Cement Association. 2007.

McQuilkin, Alex. "Consumer Demand Drives Green Construction Growth". *Green Real Estate Investing News*. 13 Sept. 2010. Web. 30 May 2011.

National Ready Mixed Concrete Association. Web. 30 May 2011. <http://www.nrmca.org>

National Center for Manufacturing Sciences. Web. 3 June 2011. <http://www.ncms.org>

PCA Economic Research. Portland Cement Association. 30 May 2011. <https://www.cement.org/econ>

Portland Cement Association. Web. 30 May 2011. <http://www.cement.org>

Price, Lynn. "Global Energy Use, CO₂ Emissions and the Potential for Reduction in the Cement Industry". Presentation. September 2006.

Steelnet: the Steel Manufacturers Association. Steel Manufacturers Association. Web. 30 May 2011. <http://www.steelnet.org>

Stewart, Holly and Abigail Mayo. "Metallurgical Coal Primer". Howard Weil Incorporated. Dec. 2010.

Stubbles, Dr. John. "Carbon "Footprints" in U.S. Steelmaking". Steel Manufacturers Association. 2007. Web. 30 May 2011.

Stubbles, Dr. John. "Energy Use in the U.S. Steel Industry: An Historical Perspective and Future Opportunities". Energetic, Inc. Sept. 2000. Web. 30 May 2011.

Suchorski, David. "Chemical Admixtures for Concrete". ACI Education Bulletin E4-03. American Concrete Institute. 2003.

Sustainable Forestry Initiative. Web. 30 May 2011. <http://www.sfiprogram.org>

U.S. Department of Energy. "Meeting Energy Efficiency and Emissions Reduction Goals in the US Steel Industry: A Need for Breakthrough Production Technologies". March 2011.

U.S. Energy Information Administration. Web. 30 May 2011. <http://www.eia.gov>

U.S. Environmental Protection Agency. Web. 30 May 2011. <http://www.epa.gov>

U.S. Environmental Protection Agency. "Quantifying Greenhouse Gas Emissions from Key Industrial Sectors in the United States". May 2008.

U.S. Environmental Protection Agency. "Profile of the Iron and Steel Industry". EPA Office of Compliance Sector Notebook Project. September 1995.

U.S. Environmental Protection Agency. "Quantifying Greenhouse Gas Emissions from Key Industrial Sectors in the United States". May 2008.

Van Oss, H. "Background Facts and Issues Concerning Cement and Cement Data". U.S. Geological Survey. 2005.

Van Oss, H. "Annual Mineral Commodity Summaries for Portland Cement". U.S. Geological Survey. 2010

Weisenberger, Geoff. "The Fabrication Factor". *Modern Steel Construction*. July 2010.