Interdependence between Structural Engineering and Construction Management
Edited by Ozevin, D., Ataei, H., Modares, M., Gurgun, A., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-6-2

REDUCTION OF CO_2 EMISSIONS IN CEMENT PRODUCTION BY USING PREHEATER

HAIYAN XIE[1], PRANSHOO SOLANKI[1], ALIREZA MOJADAM[1], and WENFANG LIU[2]

[1]*Dept of Technology, Illinois State University, Normal, USA*
[2]*School of Management, Guangxi University of Science and Technology, Liuzhou, China*

Cement has a pivotal role in the construction industry. However, cement is one of the key contributors to global CO_2 emission levels. This is due to the energy-intensive nature of cement production processes. This comparative-descriptive study focuses on the potential factors to reduce the CO_2 emission level in cement production and the decision-making process of adopting new environmental-friendly technology in production. Particularly, this study compares alternative technologies in cement manufacturing to reduce CO_2 emission. It collects both the industry data and the data from Texas, which is the biggest contributor to CO_2 emission in the US, to analyze how a shift in production technology could affect CO_2 emission and eventually improve the outcomes of environment protection and energy efficiency. This paper projects a possible improvement of implementing the method of preheater-precalciner in cement production in lieu of wet and long-dry process to upgrade kilns and reduce problematic CO_2 emission. This study suggests shifting from wet and dry kilns to preheater-precalciner systems to obtain the potential benefits of CO_2 emission reduction in the cement industry.

Keywords: Air pollution, Material production, Construction management, Sustainability, Investment analysis, Technology improvement and adoption.

1 INTRODUCTION

The Cement Industry subsumes the largest industrial non-combustion source of CO_2 emission by holding a record of 4.1% of the overall global emissions in 2014 (EPA 2015). Additionally, the cement manufacture process produces combustion-related CO_2 emissions, which also constitute an additional 4% of the total global emissions (Gibbs *et al*. 2000). Hence, the cement manufacture process by itself accounts for about 8% of the total global CO_2 emission. It is also in urgent need to control CO_2 emissions in the United States, which is the 3rd largest cement producer in the world (USGS 2015). The focus of this paper is on non-combustion related emissions in the cement industry. The purpose is to identify potential factors to reduce the CO_2 emission level in cement production. The factors can assist the decision-makers to smoothen the process to adopt new environmental-friendly technology in production. Specifically, this study collects both the industry data and the data from a particular area and compares alternative technologies.

The research goals include: (1) provide an up-to-date profile of the CO_2 emission levels of the cement industry; (2) detect and pinpoint the problematic cement production facilities to improve; (3) introduce potential improvement methods; and (4) provide in detail a transformation process for Portland cement manufacturing plants for successful adoption of new technologies.

The research seeks to answer the following questions: (1) What are the current CO_2 levels of the cement industry in the US?, (2) What are the potential CO_2 emission levels improvement rates in upgrading kilns to preheater? The shift in production technology could affect CO_2 emission and eventually improve the outcomes of environment protection and energy efficiency.

This comparative-descriptive study is conducted in a non-contrived setting. The purposes of study the production technologies affecting CO_2 emissions and eventually improve the outcomes of environment protection and energy efficiency. After compares alternative technologies in cement manufacturing to reduce CO_2 emissions in the literature review, this paper focuses on the influencing factors for new technology adoption. It collects both the industry data and the data from Texas, which is the biggest contributor to CO_2 emission in the US, to analyze the statuses and technical details of the controls on CO_2 emissions. This paper projects a possible improvement of implementing the method of preheater-precalciner in cement production in lieu of wet and dry process to upgrade kilns and reduce CO_2 emissions. In addition, this paper gives reasonable policy adjustments to help companies in the transformation processes.

2 LITERATURE REVIEW

2.1 Comparison of Various CO_2 Abatement Technologies

The CO_2 abatement technologies can be classified into five general categories: improving energy efficiency, alternative fuels, clinker substitution, innovative low-carbon cements, and carbon capture and storage. The clinker production is the most energy intensive step in the cement production (Hendriks *et al.* 1998). This step emits approximately 85% of overall CO_2 and consumes 80% of the energy used in the cement production. The average heat input required by wet, long dry, preheater, and precalciner were reported as 5.5, 4.1, 3.5, and 3.1, respectively (EPA 2015), which indicates that dry method is more energy efficient compared to wet method of cement production. Researchers demonstrated that preheater technology improved the energy efficiencies in cement production (Hanle *et al.* 2004 and Benhelal *et al.* 2013). The shift from wet to dry processes could reduce 50% energy usage and 20% CO_2 emission. For example, streamlining the kiln exhaust can save up to 20% of the energy input (Engin and Ari 2005). Galitsky and Price (2007) showed that installing an efficient kiln lead to 144 to 94,444 metric tons reduction in CO_2 emissions.

Coal is the most widely used fossil fuel in the cement production. It is possible to replace this fossil fuel with waste-derived fuel to save energy and reduce CO_2 emission (Hanle *et al.* 2004, Ali *et al.* 2011). The use of solid-waste-derived fuel might become the most ecologically and economically feasible method in lowering CO_2 emission in the cement industry (Mokrzycki and Uliasz-Bochenczyk 2003). However, the variation in properties of municipal solid waste is a significant drawback in their usage, which can lead to a low-quality final product (Kikuchi 2001).

Substitution of clinker with supplementary cementations materials (SCMs) is one of the most effective ways to reduce CO_2 emissions. The SCMs include fly ash, blast furnace slag and other pozzolans, which are able to form many types of blended cements (Gartner 2004, Hanle *et al.* 2004, Rehan and Nehdi 2005, Ali *et al.* 2011). For instance, Huntzinger and Eatmon (2009) evaluated CO_2 emission by substituting clinker with natural pozzolans and 100% cement kiln dust (CKD), which had insignificant impact on the cement's environmental footprint. Upon comparing 30 energy-efficient technologies, Worrell *et al.* (2001) concluded that the replacement of clinker with various additives was the most energy-efficient and cost-effective approach for the cement industry in the U.S. Kim and Worrell (2002) further concluded that such methods were viably duplicable on a global level. However, clinker substitution may result in low-quality final material (Schneider *et al.* 2011) and unacceptable or unmarketable products (Gartner 2004).

Low-carbon cements involve chemicals, which are completely different from the ordinary cement (IETD 2017). They offer significant reduction in CO_2 emissions. However, long-term sustainability and conformity of these cement products remain unproven. The innovative low-carbon cements need to gain customer acceptance.

Carbon capture and storage technologies are currently used for post-combustion CO_2 capture. Capturing and storing the CO_2 emission are effective solutions toward decreasing CO_2 emission levels, which were proven to reduce such emissions by 65-70% (Rehand and Nehdi 2005). Companies are interested in this business opportunity as well. In a recent study, an Australian company is planning to capture carbon emissions and convert it into solid carbonates (Guardian.com 2017). These carbonates have the potential to be used in building products, such as concrete and plasterboard, to create green construction materials.

2.2 Influencing Factors to New Technology Adoption

Many factors may influence the adoption of new technologies in control of pollutant emissions. Researchers found different influencing factors of decision-making to executives at strategic level, managers at tactical level, and technicians at technical level. Figure 1 shows the diverse influencing factors (Beggs 2000). Particularly, executives concerned on market orientation; managers focused on creativity, risks and usefulness; while technicians prefer easiness in learning and perceived benefits (Ishida *et al.* 2017, Lee 2009).

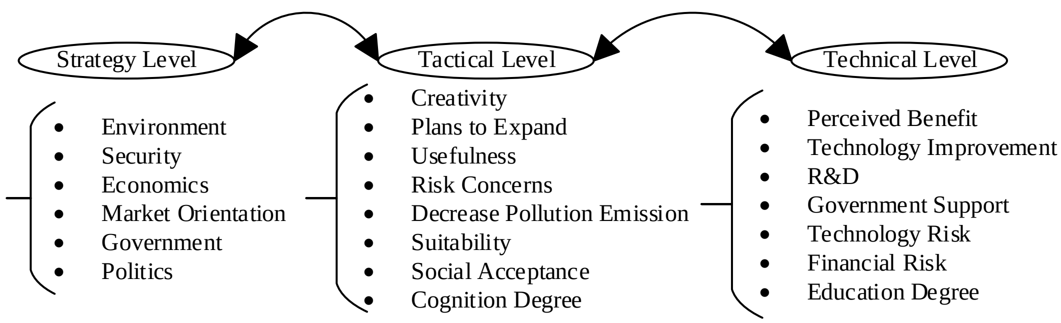
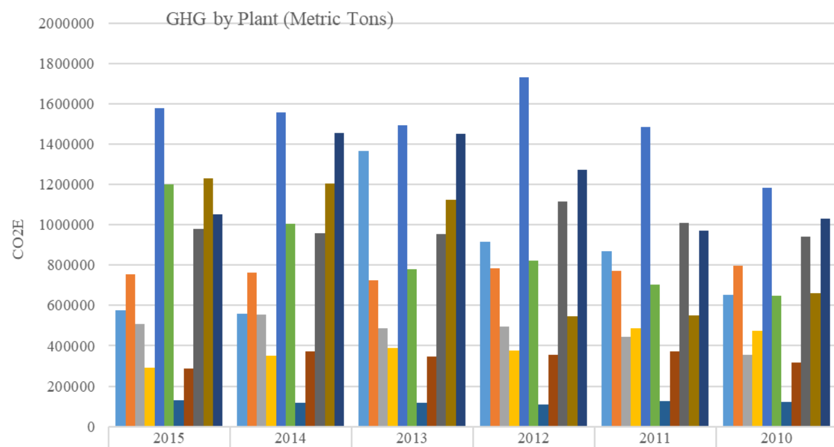


Figure 1. Diverse influencing factors.

3 DATA ANALYSIS AND DISCUSSION

Based on the database of the U.S. Environmental Protection Agency (EPA 2015), Texas accounted for 13.44% of the national total cement industry share in the non-combustion CO_2 emission and topped the list among all the states. There were 10 major and active cement production facilities in Texas (EPA 2015). Figure 2 shows their Greenhouse Gas (GHG) emission quantities over the past 6 years. Fortunately, the overall trend of the GHG emissions is decreasing. However, the GHG emission increased in the following plants: Ash Grove Cement Company, Holcim Texas Limited Partnership, Lehigh Cement Co LLLC/Waco Plant, Texas Lehigh Cement Company LP, and TXI Hunter Cement Plant. Although Ash Grove was pioneer in utilizing alternative fuels towards energy savings, it fell behind in terms of CO_2 emission levels pertaining to kiln types, because the company utilized 2 wet kilns and 1 dry kiln (USGS 2015). In terms of energy consumption, a conversion of wet or dry kiln to preheater-precalciner kiln can lead up to 40 percent increase in CO_2 emission (EPA 2015). Furthermore, such a conversion can cause a decrease in energy usage to 0.7 MMBtu /ton of cement production.



	2015	2014	2013	2012	2011	2010
Ash Grove Cement Company	576069	559764	1363796	915317	870671	651213
Alamo San Antonio Cement Plant	753290	762341	725541	786127	771784	797280
Capitol Cement Plant	506948	554230	485339	496935	445170	354667
Cemex Construction Materials South LLC	289694	350055	388469	376268	486803	473927
Cemex Construction Materials South, LLC	1580028	1557776	1494923	1729720	1482686	1182943
Holcim Texas Limited Partnership	1202046	1005020	781529	823891	702844	649166
Lehigh Cement Co LLC / Waco Plant	132123	116020	118315	110135	124505	122968
Lone Star Industries, Inc. /dba/ BUZZI UNICEM USA	288274	371051	344948	355097	371598	316778
Texas Lehigh Cement Company	978167	956245	953036	1113493	1010368	940974
TXI Hunter Cement Plant	1231790	1202912	1121981	546234	551893	662563
TXI Operations	1052468	1454146	1449259	1271535	971361	1031856

Figure 2. Greenhouse Gas (GHG) emission quantities (Data Source: EPA 2015).

4 CO_2 REDUCTION ESTIMATES

A conversion from wet or dry kiln to preheater-precalciner can lead to between 150 to 460 lb / (ton cement) reduction in CO_2 emission levels. Table 1 shows the differences that such conversion can make in the reduction of the emission levels of several Texan cement plants, including Ash Grove, Cemex, and Lehigh (EPA 2015). Figure 3 shows the results of these 3 companies when converting to 1 preheater and 1 precalciner in terms of reduction in CO_2 emission levels. Overall, this conversion can lead up to almost half million metric-ton of reduction in CO_2 emission levels, which accounts for almost 6% of the overall GHG emission quantity from the Texan cement industry.

The entire CO_2 reduction can be estimated in this method. Texas is responsible for 13.4% and almost 9 million metric tons of the overall industrial CO_2 emission in the U.S. If this conversion is used in the entire cement industry, there will be a reduction of approximately 13,840,000 metric tons of CO_2 emission. This amount leads to 20 percent of all industrial CO_2 emissions in the U.S. However, it is important to note that such a conversion calls for an investment of $96 million dollars /ton of cement production annually. In addition, operation and maintenance costs can be around $0.08 million dollars per ton cement (EPA 2015).

Table 1. Projections of Adoption of New Technology.

Facility	Kiln Type	Annual Production	GHG	GHG Reduction
Ash Grove	2 wet 1 dry	575,809	576,069	40,000-12,000
Cemex	1 preheater	1,585,163	1,580,208	108,000-330,000
Lehigh	1 wet	132,474	132,123	9,000-28,000
			Total	157,000-478,000

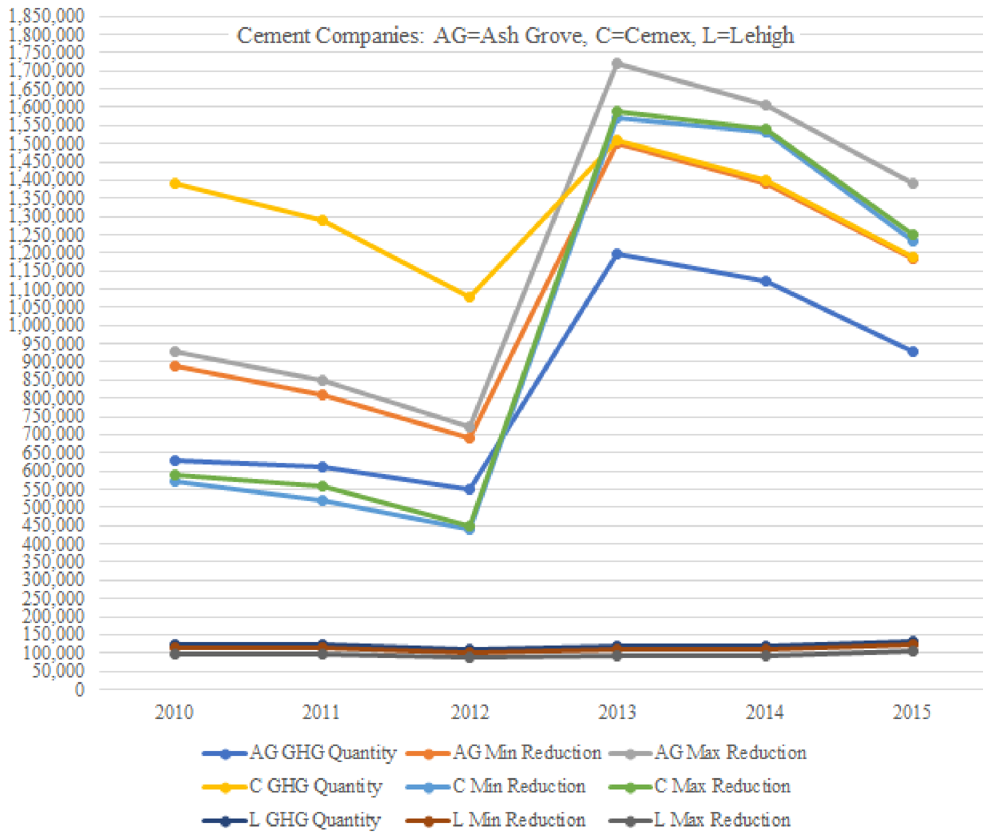


Figure 3. CO_2 emission projection (Data Source: EPA 2015).

5 CONCLUSIONS

This study focuses on the comparison between different cement production processes of different technologies. By capitalizing on the available data, this study evaluates the levels of CO_2 emissions among various cement production facilities. The results indicate that shifting from wet and dry kilns to preheater-precalciner systems has potential to reduce CO_2 emissions in the cement industry. In the final analysis, the data shows that the shift can reduce the CO2 emission levels up to almost 6% in the overall emission levels of the Texan cement industry. This saving is approximately 0.8% of the overall industrial CO_2 emission in the U.S. During this research, data confidentiality hindered the study greatly. For example, companies keep confidentiality on the data of the fuel consumption in a kiln and the production capacity of each kiln. This research is the start of a comprehensive look into the cement industry about technology improvement and adoption. The research would encourage the exploration of further methods towards more efficient cement-production with reduced CO_2 emission and energy consumption in the country.

Acknowledgments

This research is partially supported by the University Research Grant of Illinois State University (XIE2016) and the grant of Research on Multi Transportation network of Guangxi District Logistics on the Background of "One Belt and One Road", Guangxi Education Department (KY2016YB233).

References

Ali, M. B., Saidur, R., and Hossain, M. S., A Review on Emission Analysis in Cement Industries, *Renewable and Sustainable Energy Reviews*, 15(5), 2252-2261, 2011.

Benhelal, E., Zahedi, G., Shamsaei, E., and Bahadori, A., Global Strategies and Potentials to Curb CO_2 Emissions in Cement Industry, *Journal of Cleaner Production*, 51, 142-161, 2013.

Beggs, T. A., Influences and Barriers to the Adoption of Instructional Technology, 2000. Retrieved from http://files.eric.ed.gov/fulltext/ED446764.pdf on September 1, 2017.

Engin, T., and Ari, V., Energy Auditing and Recovery for Dry Type Cement Rotary Kiln Systems - A Case Study, *Energy Conversion and Management*, 46(4), 551-562, 2005.

EPA, United States Environmental Protection Agency 2015 Report, 2015.

Galitsky, C., and Price, L., *Opportunities for Improving Energy Efficiency, Reducing Pollution and Increasing Economic Output in Chinese Cement Kilns*, Proceedings of the 2007 ACEEE Summer Study on Energy Efficiency in Industry, 2007.

Guardian.com, Australian Firm Unveils Plan to Convert Carbon Emissions into 'Green' Concrete: Initiative to Convert CO_2 into Solid Carbonates Aims to Produce Building Materials on Commercial Scale by 2020, Guardian News and Media Limited. Retrieved from https://www.theguardian. com/environment/2017/aug/25/green-building-materials-carbon-capture-technology-ready-by-2020-says-manufacturer on September 1, 2017.

Gartner, E., Industrially Interesting Approaches to "Low-CO_2 Cements", *Cement and Concrete Research*, 34(9), 1489-1498, 2004.

Gibbs, M. J., Soyka, P., Conneely, D., and Kruger, M., CO_2 Emissions from Cement Production, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, 2000.

Hanle, L. J., Jayaraman, K. R., and Smith, J. S., *CO_2 Emissions Profile of the US Cement Industry*, Washington DC: Environmental Protection Agency, 2004.

Hendriks, C. A., Worrell, E., De Jager, D., Blok, K., and Riemer, P., *Emission Reduction of Greenhouse Gases from the Cement Industry*, Proceedings of the Fourth International Conference on Greenhouse Gas Control Technologies, 939-944, 1998.

Huntzinger, D. N. and Eatmon, T. D., A Life-Cycle Assessment of Portland Cement Manufacturing: Comparing the Traditional Process with Alternative Technologies, *Journal of Cleaner Production*, 17(7), 668-675, 2009.

IETD, Low-Carbon or Carbon-Negative Alternatives to Portland Cement, The Institute for Industrial Productivity, 2017. Retrieved from http://ietd.iipnetwork.org/content/low-carbon-or-carbon-negative-alternatives-portland-cement by September 1, 2017.

Ishida, S., Magnusson, M., and Nagahira, A., Factors Influencing Japanese Auto Suppliers' Predictions about the Future of New Technologies–An Exploratory Study of Electric Vehicles, *Futures*, 89, 38-59, 2017.

Kikuchi, R., Recycling of Municipal Solid Waste for Cement Production: Pilot-Scale Test for Transforming Incineration Ash of Solid Waste into Cement Clinker, *Conservation and Recycling*, 31(2), 137-147, 2001.

Kim, Y., and Worrell, E., CO_2 Emission Trends in The Cement Industry: An International Comparison, *Mitigation and Adaptation Strategies for Global Change*, 7(2), 115-133, 2002.

Lee, M. C., Factors Influencing the Adoption of Internet Banking: An Integration of TAM and TPB with Perceived Risk and Perceived Benefit, *Electronic Commerce Res. and Applns.*, 8(3), 130-141, 2009.

Mokrzycki, E., and Uliasz-Bocheńczyk, A., Alternative Fuels for The Cement Industry, *Applied Energy*, 74(1), 95-100, 2003.

Rehan, R., and Nehdi, M., CO_2 Emissions and Climate Change: Policy Implications for the Cement Industry. *Environmental Science & Policy*, 8(2), 105-114, 2005.

Schneider, M., Romer, M., Tschudin, M., and Bolio, H., Sustainable Cement Production-Present and Future, *Cement and Concrete Research*, 41(7), 642-650, 2011.

USGS, American Council for an Energy-Efficient Economy. PCA, Portland Cement Association Annual Reports USGS; US Geological Survey Annual and Quarterly Reports, 2015.

Worrell, E., Price, L., Martin, N., Hendriks, C., and Meida, L. O., CO_2 Emissions from the Global Cement Industry, *Annual Review of Energy and the Environment*, 26(1), 303-329, 2001.