EVALUATING THE FEASIBILITY OF USING CORN ASH AND WOOD ASH IN CONCRETE IN FLORIDA

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my beloved parents, Kiran Sathe and Anita Sathe who have continuously supported my efforts of pursuing a master's degree. To my elder brother, Angad Sathe, for encouraging and believing in me. To all friends and relatives, without whom this would not have been possible.

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The use of fly ash in concrete has seen a steady rise in the last few years. Several government agencies have specified a minimum quantity of fly ash as a substitute for cement in concrete. For example, the Florida Department of Transportation requires a minimum of 18% by weight of the total cementitious materials. In recent years, the generation of fly ash has reduced due to the decreasing reliance on using coal power plants. Therefore, to avoid a situation of fly ash shortage, it is necessary to start looking at alternative options.

Wood ash and corn ash have been considered as potential replacements to fly ash in concrete in countries like Nigeria and India. United States is the largest producer of corn with majority of the production in the Midwest. Therefore, there is potential of using corn ash as a substitute for cement and fly ash. The only problem is the availability and the transportation concerns in Florida. Similarly, wood waste is available in plenty in Florida with almost 3 million tons being landfilled. As there are several biomass plants in Florida which use wood biomass to generate electricity, the wood waste can be potentially used to partially satisfy the wood ash as a replacement material to fly ash in concrete.

In this study, it is shown that corn ash and wood ash have the potential of meeting 3% and 37% of the quantity of fly ash needed to replace Portland cement in production of 3000 psi concrete in Florida. The environmental impacts of using fly ash along with corn ash and wood ash are also calculated and compared. These impacts consider the energy required to transport wood and corn ash to the concrete gate in Orlando and Miami from their source location. Extensive comparison of all the wastes shows that the transportation energy emissions for wood ash and corn ash are higher than fly ash in Orlando and lower in Miami. Similar study and analysis shows that the cost per ton of wood ash and corn ash are higher than that of fly ash by $4/t and $25/t respectively.

CHAPTER 1
INTRODUCTION

1.1 Concrete Production and Global Warming Emissions

Concrete is one of the widely-used construction materials in the world today (Olafusi S. and Olutoge A. 2012). It is estimated that concrete production would be around 18 billion tons by 2050 (Aprianti E et al., 2015). This has put a large strain on raw materials and non-renewable natural resources. Construction is said to be a significant source of greenhouse gas emissions (Junnila S. and Horvath A. 2003). Therefore, increase in concrete production will lead to increase in Greenhouse Gas emissions (GHG). Concrete consists of cement, fine aggregates and coarse aggregates along with water in proper proportions. Each of these constituents contributes in the strength of concrete by forming calcium-silicate-hydrate called as the process of hydration. Ordinary Portland Cement (OPC) is an important ingredient in concrete. The increase in concrete demand has meant that the cement production has increased causing an increase in carbon emissions. The cement production in 2012 was approximately 3,800 million metric tons while in 2016 it increased to 4,200 million metric tons (Statista). The increase in cement consumption has been because of better infrastructure facilities, improved standard of living caused by increasing population. It is estimated that for every ton of cement produced, around 0.73-0.99 tons of CO_2 is emitted. (Hasanbeigi et al., 2012). It is estimated that half of these emissions are due to the combustion of fossil fuels as production of cement requires about 4-5GJ/ton of energy (Celik K. et al., 2015). This increase in carbon emissions has led to expanded efforts on studying alternative materials as a replacement to cement in concrete.

Use of industrial waste like fly ash, blast furnace slag and silica fume in concrete has been going on for a long time now. Use of these waste products has prevented 15 million metric tons from entering landfills. Fly ash and blast furnace slag are byproducts of coal combustion and iron and steel manufacturing process respectively. As these are waste products having efficient pozzolan properties, their use in concrete has produced positive results. The government has promoted the use of fly ash in concrete with the Florida Department of Transportation (FDOT) having a minimum 18% requirement of fly ash in concrete. In recent years, however, the generation of fly ash has reduced because of the ill effects of coal combustion. But the demand for fly ash has remained constant. With the increasing reliance on fly ash in the production of concrete, the reduction in the availability of fly ash is a source of concern. Therefore, it has become necessary to look for alternative options as a potential replacement. Corn ash and wood ash are the relatively new products that have been proposed for use as partial replacements to cement. These products are found to have good pozzolan properties and can be a good replacement to fly ash in concrete. Wood waste is used in biomass plants as a raw material for generating renewable energy. These biomass plants emit wood ash as a byproduct like fly ash in coal combustion process. Thus, the potential of wood ash generation is significant. 20% of the solid waste generated in Florida consists of wood and yard trimmings (MSW). Similarly, corn waste generation is significant as United States is the largest producer of corn. Therefore, corn waste can also be considered for using as a raw material in biomass plants. The ash generated, can be used as a partial replacement to fly ash in concrete.

1.2 Objective

The aim of this thesis was to

1. Review past research in evaluating performance of corn ash and wood ash in concrete production and compare their physical and chemical properties to normal fly ash. This past research is further used to find the optimum cement replacement percent of corn ash and wood ash in production of 3000 psi concrete.

2. Based on the optimum percentage of wood ash and corn ash determined in part 1, calculate the amount and availability of wood ash and corn ash required for concrete production (less than 3500 psi) in Florida.

3. Calculate and compare environmental impacts in terms of energy required for transporting fly ash, corn ash and wood ash to Orlando and Miami.

4. Find and compare the cost per ton of fly ash, corn ash and wood ash delivered at concrete plants in Orlando and Miami.

1.3 Thesis Structure

Research consists of five chapters which are categorized as follows:

Chapter 1: The first chapter consisted of understanding the need for looking at different sources as a replacement to fly ash in concrete. The result for the increase in concrete and cement production is because of rising population levels. It included studying the demand and supply statistics of fly ash which has made it necessary to look at alternative options like wood and corn ash.

Chapter 2: Literature review covered the interrelationship of concrete and sustainable construction. It included the contribution of concrete and its raw materials in producing carbon emissions. Literature covered research done on the use of fly ash, wood ash and corn ash in concrete all over the world. Each material was reviewed in detail for their extraction process, individual characteristics and their properties when used in concrete. This section includes the following topics:

1. Interrelationship of concrete and sustainable construction
2. Supplementary Cementitious materials
3. Fly Ash
4. Wood Ash
5. Corn Ash

Chapter 3: Research Methodology included comparison of the physical and chemical properties of concrete with wood ash and corn ash with normal fly ash. It also included reviewing literature in finding the optimum replacement percentage of corn ash and wood ash to get 3000 psi strength concrete. The replacement percentages resulted in finding the annual requirement of corn ash and wood ash in Florida. The focus of the study only covered annual wood ash and corn ash requirement for low strength concrete (less than 3500 psi). The source of wood ash was the potential wood waste that would be used in biomass plants to generate electricity. Currently, corn ash is not used as a replacement material in concrete. The corn waste was assumed to be used in biomass plants to generate electricity. Therefore, the source of corn ash was taken as a biomass plant as well. For calculating environmental impacts, two locations were selected: Orlando and Miami. The sources of wood ash, corn ash and fly ash were taken nearest to both the locations. Environmental impacts of using these waste materials were calculated in terms of the energy required to transport the materials to the concrete gate in Orlando and Miami. The cost per ton of fly ash, wood ash and corn ash were obtained to compare the differences.

Chapter 4: This chapter analyzed physical and chemical properties compared in chapter 3. The chapter also included calculating the annual demand and requirement of wood ash and corn ash for use in low strength concrete in Florida. It analyzed the energy spent in transporting wood ash and corn ash to concrete gate in Orlando and Miami. It also compared the cost per ton of fly ash with that of wood ash and corn ash.

Chapter 5: The final chapter discussed the findings of the study. This chapter will end with future recommendations and scope of further research.

CHAPTER 2
LITERATURE REVIEW

2.1 Sustainability and the Concrete Industry

The ready-mix concrete industry is focused on providing a sustainable development solution to meet the needs of the present generation without affecting the ability of the future generations to meet their own needs. Project owners, developers, contractors and product manufacturers are affected by the challenges of maintaining sustainable development especially since their actions have an economic, environmental and social impact on the planet. There are numerous organizations that have focused their attention on developing ways to reduce the carbon footprint of concrete through the development of innovative cement and concrete mixtures. Typically, a concrete mixture is 7-15% cement, 60-75% aggregate and 15-20% water. Figure 2-1 shows the life-cycle of concrete which involves material acquisition to product recycling. The manufacture of Portland cement is the third most energy intensive process after aluminum and steel. A few of energy reduction process have involved replacement of dry production facilities with wet processing plants. The cement industry has also moved away from petroleum based fuel use. To produce 1 ton of Portland cement, 1.6 ton of raw materials like limestone and clay are required. The concrete industry is one of the two largest producers of CO_2, having 10% of worldwide emissions out of which 50% are from chemical processes and 40% are from burning fuel. The chemical processes include calcination of raw materials which is a part of the manufacturing process. In 2010, U.S was the third largest cement manufacturing country after China 1,814Mt (2,000 million metric tons) and India 191Mt (210 million tons).

The U.S cement industry accounts for 1.5% of U.S CO_2 emission. According to a survey done by the Portland Cement Association (PCA), it was estimated that 1 ton (2205lbs) of cement produces 1 ton (1984 to 2285lbs) of CO_2. The average cement content is 7-15% by weight depending on the concrete mix. The average quantity of cement is 420 lbs./yd^3. Thus, approximately 170-500 lbs./yd^3 of CO_2 is embodied per cubic yard of concrete. Per the National Ready Mixed Concrete Association (NRMCA), the carbon footprint, embodied energy, potable water, waste and recycled content are the key performance indicators that are measured with regards to product sustainability. Figure 2-2 shows the temperature differences over the last decade because of rising temperatures. Per the data obtained from NRMCA, figure 2-3 shows the percentage CO_2 emissions in transportation, residential, industrial and commercial sector. The cement production in the United States and the world is observed in Figure 2-4 and Figure 2-5. The global CO2 emissions have seen a steady rise in the last decade Figure 2-6. From Figure 2-7, concrete and cement require relatively less production energy when compared with other products like steel, aluminum, stainless steel and glass (Penttala V. 1997).

The U.S Concrete industry has initiated the P2P (Prescriptive to Performance Specifications for Concrete) initiative which provided concrete manufacturers more flexibility per their requirements. It can also help to reduce the environmental impacts. It is observed that the construction industry has unnecessary requirements regarding Portland cement and the limits of using supplementary cementitious materials in concrete. This P2P initiative proposes to eliminate certain prerequisites and evolve the use of cement and other materials per the specific job requirements. This initiative can help reduce the environmental impact of concrete (P2P).

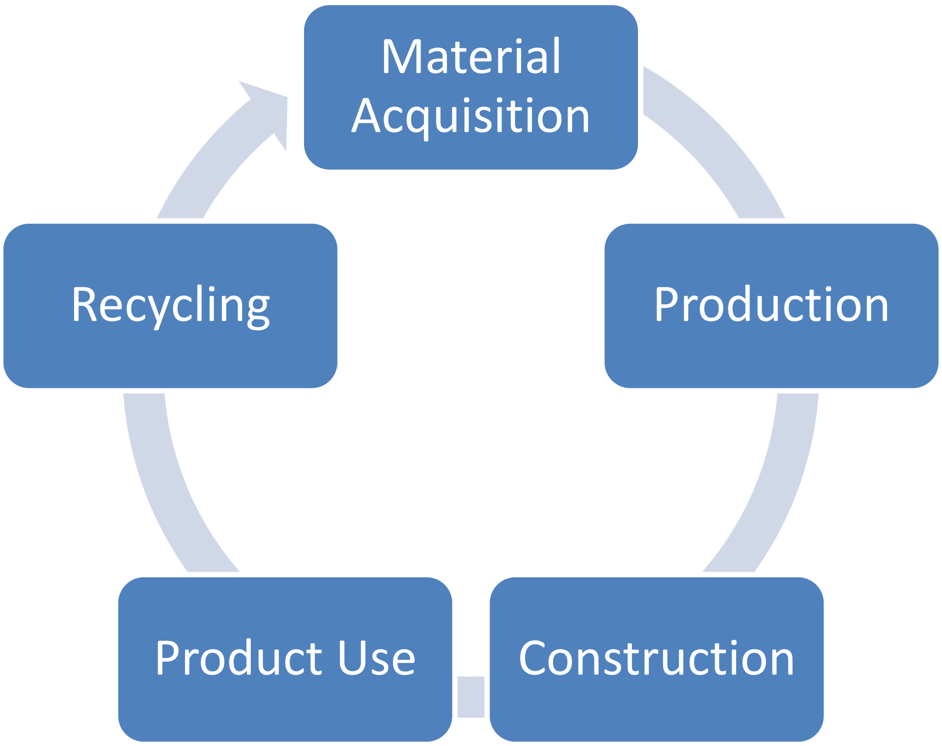


Figure 2-1. Life cycle of concrete

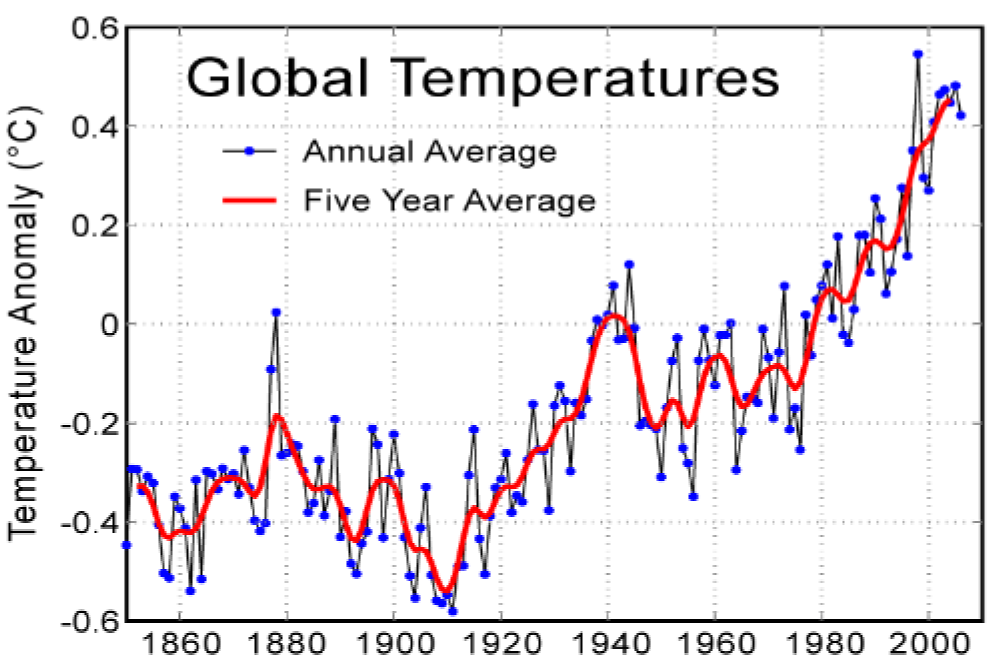


Figure 2-2. Temperature difference over the last few centuries (adopted from NRMCA Concrete CO_2 fact sheet)

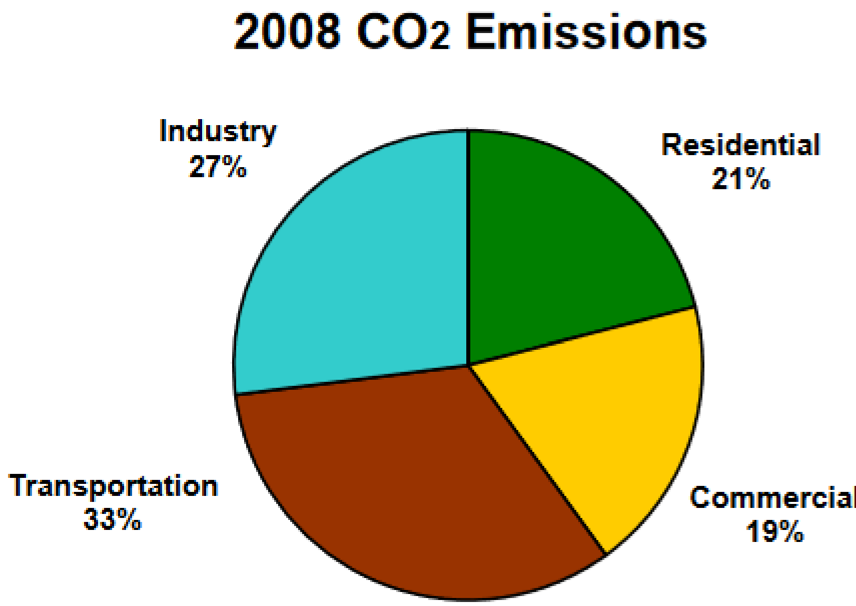


Figure 2-3. Pie chart with percentage carbon dioxide emissions (adopted from NRMCA Concrete CO_2 fact sheet)

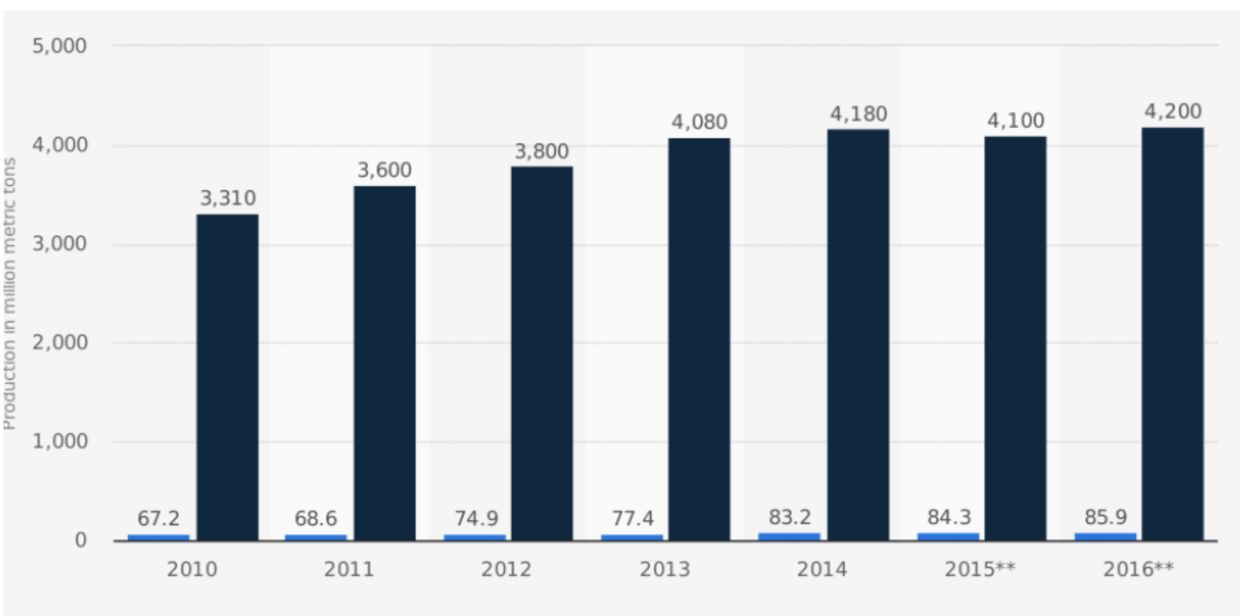


Figure 2-4. Cement Production in United States and the World (adopted from Statista)

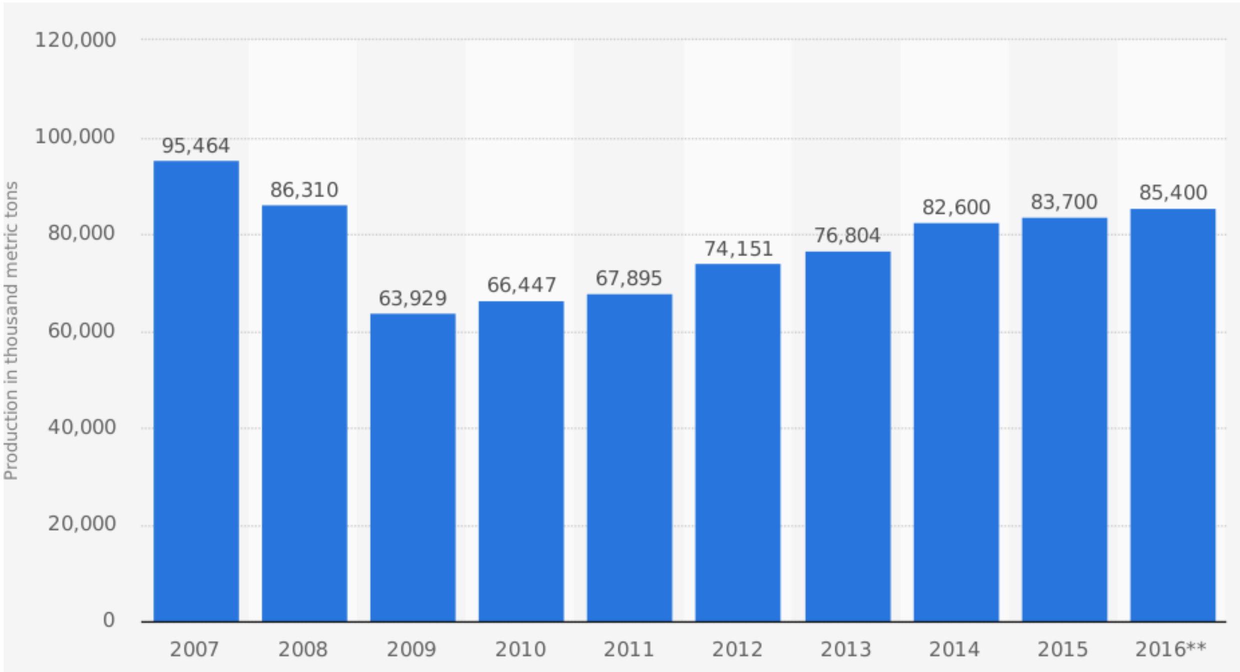


Figure 2-5. Domestic Cement Production in the United States (adopted from Statista)

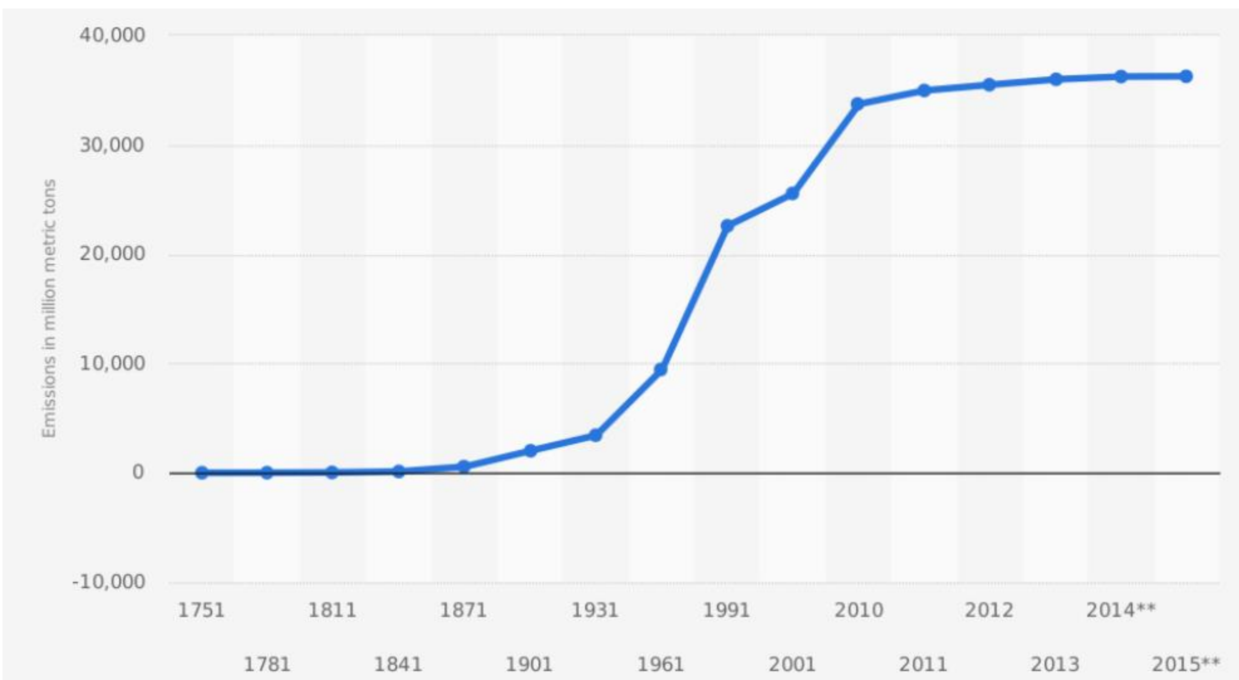


Figure 2-6. Global CO_2 emissions in million metric tons (adopted from Statista)

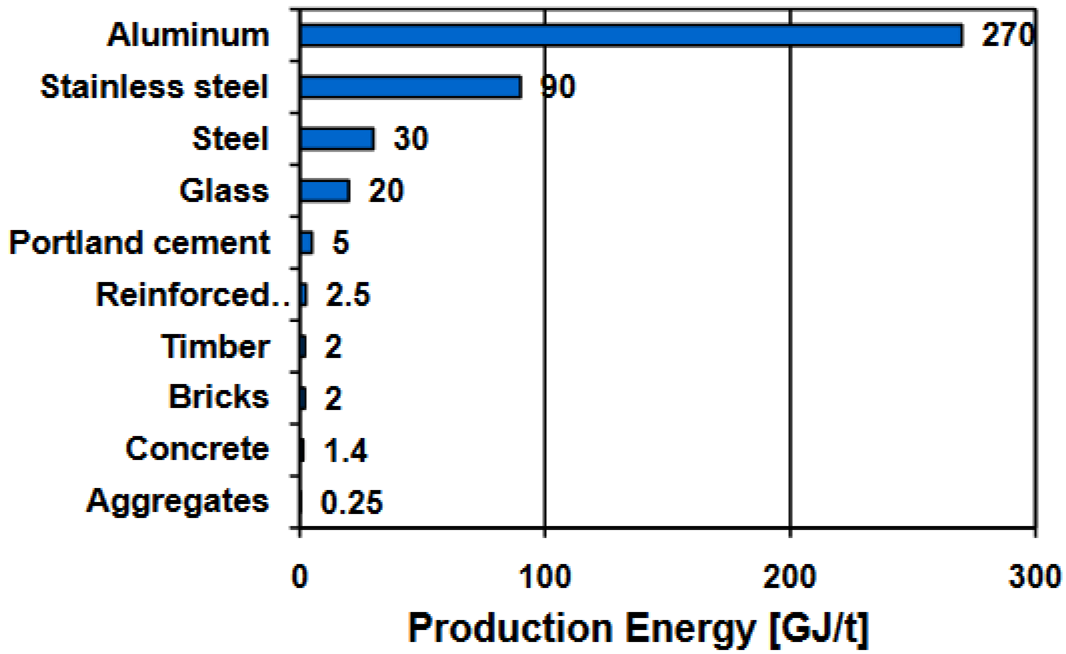


Figure 2-7. Production energy of different materials (adopted from: Penttala V. 1997)

2.2 Supplementary Cementitious Materials

Concrete is a combination of cement, water, sand and aggregate. SCM's can be divided in two categories based on the type of reaction they undergo: hydraulic and pozzolan. Hydraulic materials react directly with water to form cementitious compounds while pozzolan materials react to form C-S-H gel in the presence of water that has concrete like properties. The purpose of using SCM's like fly ash, slag cement is to reduce the cement content in concrete. Industrial wastes such as fly ash and blast furnace slag along with agricultural wastes like corn cob ash and wood ash are being used as supplementary materials for partial replacement of cement. These materials contain aluminum oxide, silica oxide which react with calcium hydroxide to form compounds having cementitious properties which are called pozzolan. High early strength of concrete can be produced by the highly reactive silica in pozzolan. Another advantage of using these SCM's is that their percentages can be varied to get the required strength characteristics of concrete. It is easy to improve the performance of concrete by using them as admixtures as well. By reusing these wastes, it can help reduce cement production resulting in reduction in cost of production of concrete. Use of these SCM's can reduce the waste sent to landfills, reduce raw materials, lesser energy of production and reduced CO_2 emissions.

There are large quantities of waste materials all over the world from different sectors like industrial, agricultural both in urban and suburban areas. These wastes if not treated properly can be hazardous. The waste quantity also has gone on to increase tremendously with the increasing population. Large amount of land is lost in landfilling operations to dump these wastes. The diversion of these wastes to useful activities or products can help reduce the burden on waste disposal. It can also help save valuable land from landfilling. Research has therefore grown a lot as to appropriate utilization of these waste into useful products. Fly ash and blast furnace slag have proved to be good replacement to cement in concrete. Wood ash and Corn Cob ash have also been used as cement replacement materials in different countries. All the four materials possess cementitious properties which help react with aggregates and sand to form concrete. Figure 2-8 gives the limiting values of Supplementary Cementitious Materials. Per a survey by the National ready-mix concrete Association, the different cementitious percentage used per cubic yard of concrete was found out. Figure 2-9 shows the the different SCM's per cubic yard of concrete. Research conducted by Malhotra (2012) that concrete mixtures containing higher percentages of SCM's have shown to underperform in tests conducted in accordance with ASTM C672/C672M. It is observed that the use of SCM's increases the setting time and decreases the early age strength in concrete. This can be beneficial in warm weather conditions like Florida but may be problematic in cooler weather. Research has shown that different fly ash samples give significantly different results when 11 different fly ash sources were used to illustrate 20% replacement. (Malhotra and Ramezanianpour 1994). Concrete temperature also influences these properties. Therefore, restricting the percentages does not definitely lead to good properties. Some of the observed benefits of SCM's are:

1. Improved resistance to sulfate attack
2. Better concrete durability.
3. Continued improvement in strength at later ages which can improve the life of structures
4. Sustainable construction having lower emissions.

A survey conducted by the American Coal Ash Association in 2012 highlighted different parameters to find out the use of these materials in construction. It observed that there can be a potential increase in the use of SCM from the existing 102lbs to 144 lbs./yd3 produced. Assuming all the increase is attributed to fly ash and slag cement, and the production levels of concrete continue to rise, the percentage use of fly ash and slag cement will rise from 41% to an all-time high of 61%. This will mean a strain on the availability of fly ash and slag cement assuming the current reduction in the supply of these two materials continues.

Table 1: Limits on cementitious materials for concrete assigned to Exposure Class F3 (Table 26.4.2.2(b) in ACI 318-14)

Cementitious materials	Maximum percent of total cementitious materials by mass
Fly ash or other pozzolans conforming to ASTM C618	25
Slag cement conforming to ASTM C989	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or other pozzolans and silica fume	35
Total of fly ash or other pozzolans, slag cement and silica fume	50

Figure 2-8. ASTM specifications showing maximum percentage replacements (adopted from NRMCA specification)

	<250,000yd3	250 to 1 Million yd3	>1 Million yd3	All
Portland Cement	451	466	454	457
Fly Ash	63	84	86	83
Slag Cement	43	13	18	19
Total SCM	106	98	104	102

Figure 2-9. Production numbers in terms of lbs of cementitious material per cubic yard produced (adopted from NRMCA SCM Survey 2012)

2.3 Corn Ash

According to the United States Department of Agriculture, more than 90 million acres of corn plantations are grown in the U.S with the majority of the crop grown in the Heartland region. Corn is used majorly for livestock feed, in food and industrial products like starch, sweeteners corn oil, beverage and fuel ethanol. Corn production has increased from a low of 60.2 million in 1983 to more than 90 million in 2015. Figure 2-10 shows the statistics of feed grain production in the year 2016/17. 95% of the production is dominated by corn, while oat, barley and sorghum make up the remaining 5%. Figure 2-11 shows the prominent rise in the yield of corn over the last century. Although, the area allotted for corn plantation has remained fairly constant which means that better agricultural techniques have helped to improve the yield. Figure 2-12 shows the different types of domestic uses of corn stover like alcohol for fuel use, for livestock feed and other seed and industrial uses. Figure 2-13 provides the production statistics of corn in different counties of Florida.

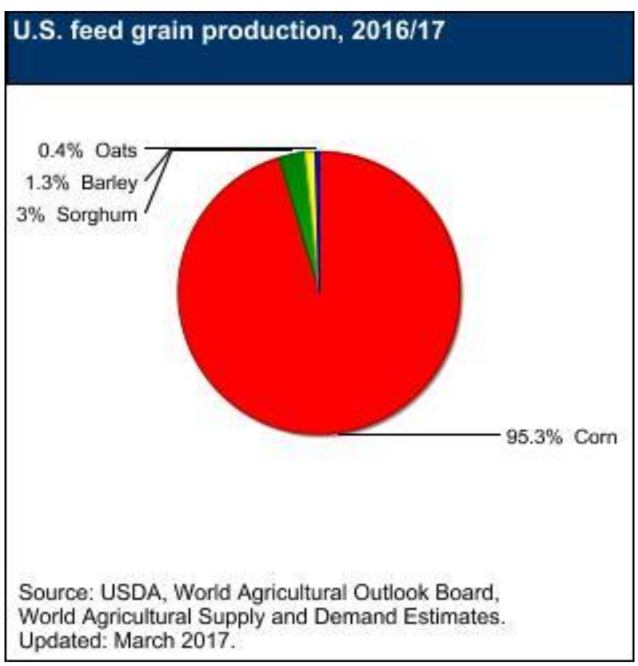


Figure 2-10. Corn Production Statistics (adopted from US Department of Agriculture)

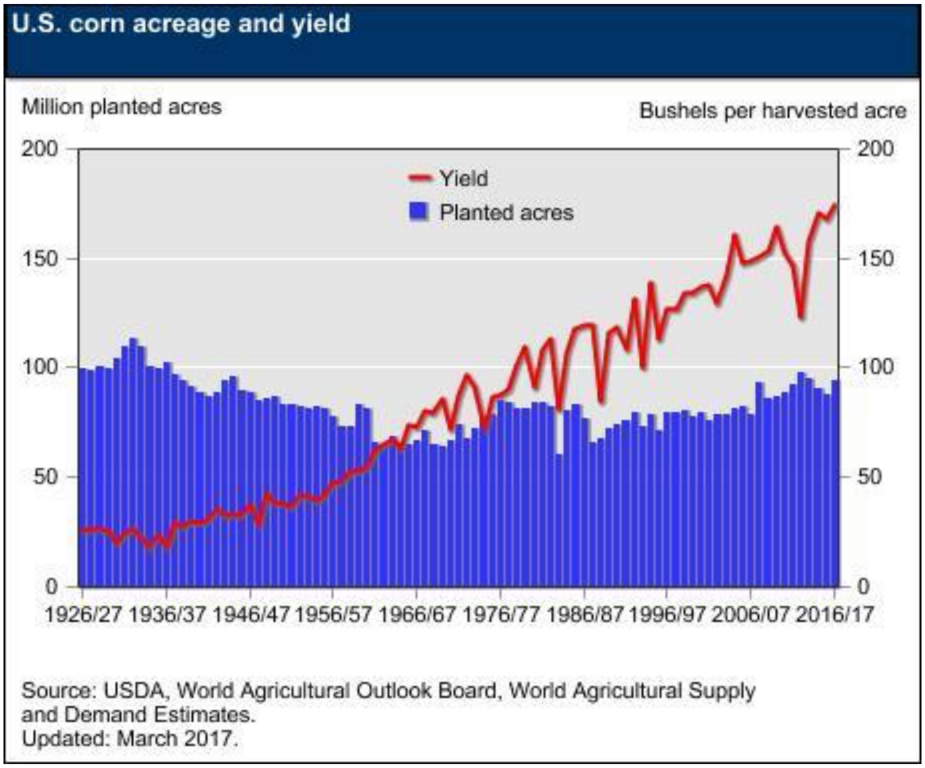


Figure 2-11. Yield of corn in the United States (adopted from US Department of Agriculture)

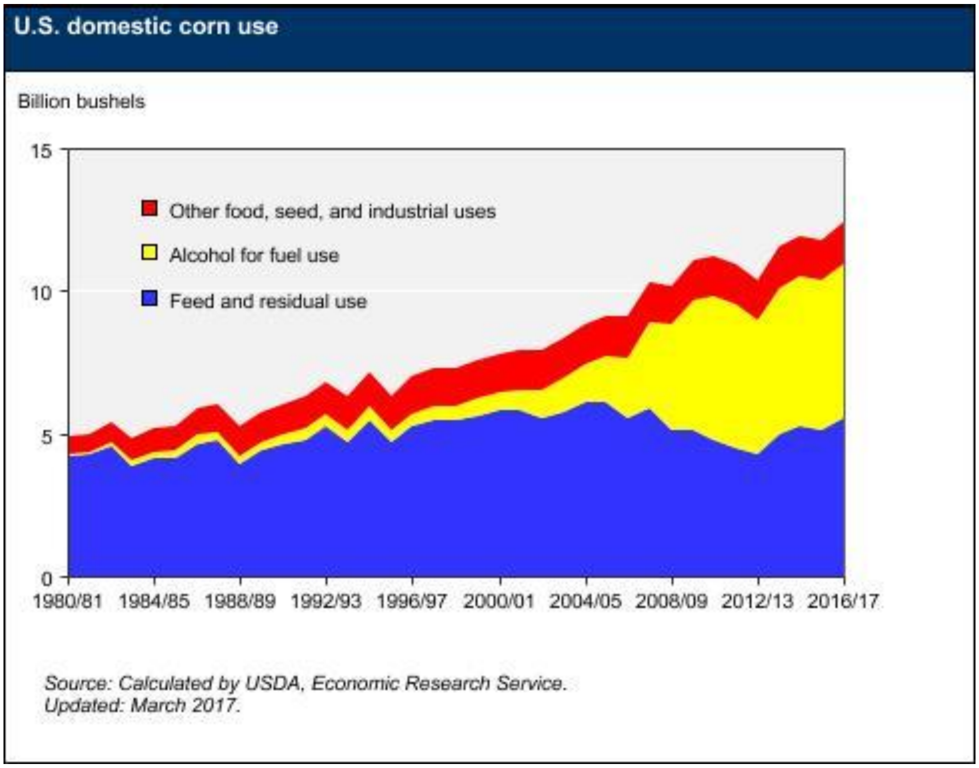
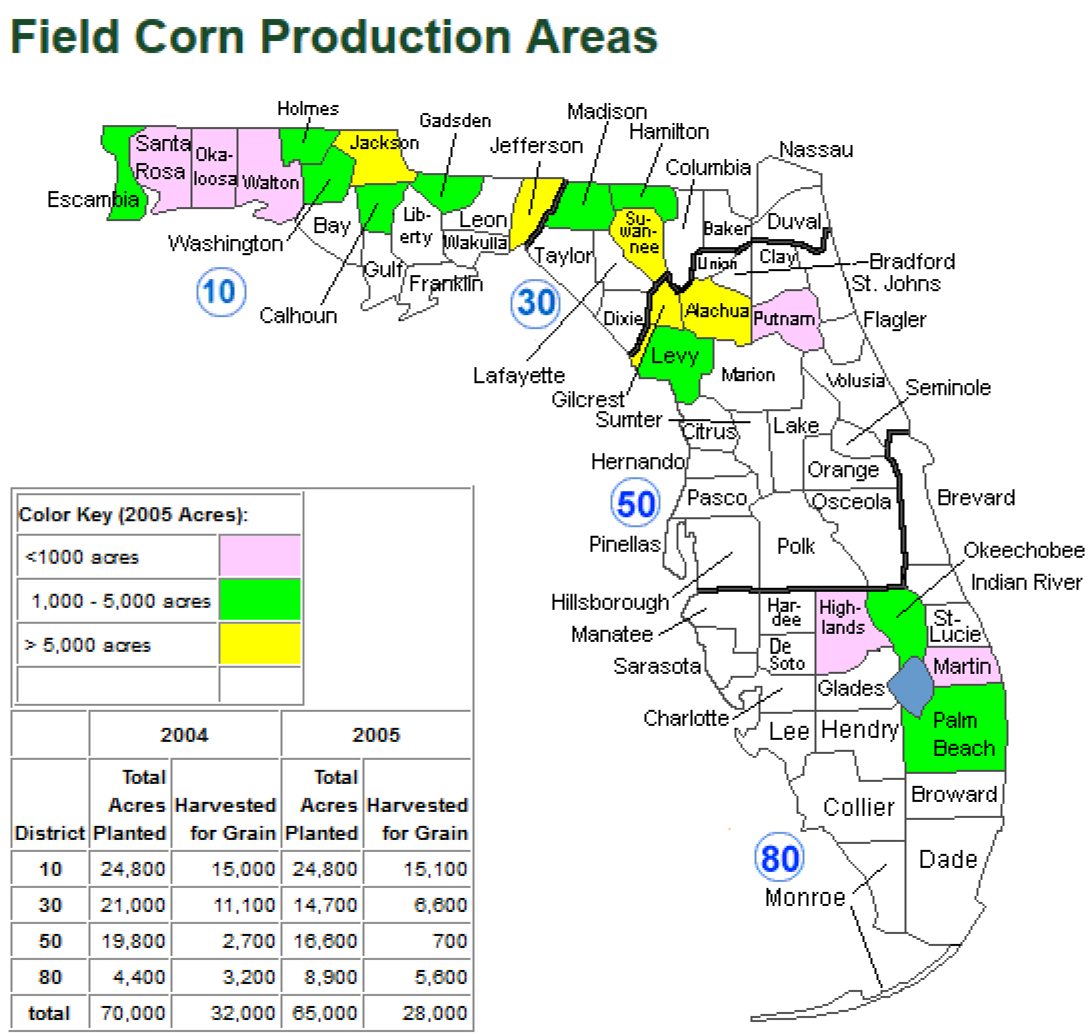


Figure 2-12. Use of Domestic Corn (adopted from US Department of Agriculture)

Corn stover is the combination of stalks, leaves and cobs that is left in the field after corn harvest. Its major use is for ethanol production. Corn stover is also used for cellulosic sugars that can be fermented into ethanol. It is estimated that corn stover could supply as much as 25% of the biofuel needed by 2030 (Koundinya V. 2009). Chemical composition of corn stover includes 70% cellulose and hemicellulose and 15-20% lignin. The cellulose and hemicellulose can be converted into ethanol while lignin can be burned as a boiler fuel for electricity generation in biomass plants. 1 ton of corn stover was found to include 15 lbs. of nitrogen (N), 6 lbs. of phosphate (P_2O_5), and 25 lbs. of Potash (K_2O) (Missouri). Corn cob and corn stover are used as a biomass feedstock. Due to similar properties, they can be used in biomass plants for electricity generation.

Corn cob is the central thick core on which the grains are borne. It is a waste product that is ultimately crushed and landfilled. The remains of corn cob after removing corn are an agricultural waste. Corn cob ash has pozzolan properties which is therefore a suitable replacement for cement in concrete production. United States is the largest producer of maize having 52% of the world production. Based on the current research, agricultural wastes such as corn cob and wood ash have a wide scope of being used in concrete production in the United States. Use of these agricultural waste products can help reduce the disposal problems that end up polluting land, air and water. However, there is potential for more research on the use of corn cob ash in concrete in the United States, despite it being one of the largest producers of corn.

Pinto et al. (2012) researched the use of corn cob as a lightweight aggregate for producing concrete. This study involved measuring the density, compressive strength and thermal insulation properties of corn cob inducted concrete. Previous research on corn cob has also focused on replacing cement with different percentages of corn cob ash to check if the concrete is per American Society of Testing Materials (ASTM) and National Institute of Science (NIS) standards. There have also been thermal conductivity and insulation tests on corn cob ash concrete. The results have shown that thermal conductivity decreases with a 25% corn cob ash replacement. The insulation tests have shown that the properties of the CCA concrete improve by replacing cement with corn cob ash (Adesanya D.A and Raheem A.A 2009). It has been found that compressive strength increases with age of curing but decreases with increase in CCA percentage. There is an increase in compressive strength of concrete which has a 10% replacement of cement with CCA. Water requirement was also found to increase with increase in percentage CCA replacement. In the Cameroon, corn is also used for beer manufacturing and breeding along with human consumption (Nkayem D. et al. 2016). They also noted that corn ash did not attain the required strength at 28 days. It was also observed that the addition of admixtures led to improvement in workability and the compressive strength of corn cob ash cement concrete. Use of accelerator helped to increase the strength at early ages (Raheem A. et al., 2009).



District	2004 Total Acres Planted	2004 Harvested for Grain	2005 Total Acres Planted	2005 Harvested for Grain
10	24,800	15,000	24,800	15,100
30	21,000	11,100	14,700	6,600
50	19,800	2,700	16,600	700
80	4,400	3,200	8,900	5,600
total	70,000	32,000	65,000	28,000

Figure 2-13: Shows the corn production statistics in Florida by county. (adopted from IFAS)

2.4 Fly Ash

Fly ash is one of the by-products of coal combustion and is used as a cementitious material in Portland cement concrete. Thermal power plant fly ash is classified in two forms; Class C and F fly ash depending on the properties of coal as well as the combustion process. Fly ash standards are set according to ASTM C618 based on their composition and properties. Class C fly ash is not permitted for use in concrete. Figure 2-14 provides the minimum chemical requirements in different types of fly ash. Figure 2-15 gives the industry standards of the minimum requirements of fly ash. The minimum silica, aluminum and iron oxide contents is required to be 70%. It is observed that the LOI value is limited to 6%. Although, ASTM C618 permits LOI values up to 12% provided there is proper documentation of the service records. The fineness retained on a 45um sieve is limited to 34. There are limits on the sulfur trioxide, moisture content, soundness, strength activity index, water requirement and uniformity requirements.

The performance of fly ash depends on the source of coal as well as the physical and chemical properties. It is found that fly ash requires 30-40% more storage space than ordinary Portland cement. Fly ash is spherical in shape increasing the flowability. The government has promoted the use of fly ash over the years to reduce the problem of disposal of fly ash. Per the American Coal Ash Association (ACAA), almost 50% of all ready-mix concrete has fly ash as a material. With the industry relying heavily on fly ash as a sustainable material, the decline in production of fly ash is a source of concern for the construction industry. To avoid a situation where we end up falling short of fly ash, it is necessary to take measures by researching alternative pozzolan materials as a replacement to fly ash and cement in concrete. Besides concrete, fly ash is also used in composite materials like metal alloys for auto parts and synthetic lumber. In recent years, the industry's reliance on coal as a source of energy has begun to decline. Generation of fly ash which was constant till 2010 has therefore began to decline as well. The decrease in production of fly ash, has not resulted in a decrease in the use of fly ash. It therefore means that higher percentage of fly ash is reused in concrete. Addition of fly ash in concrete as an admixture has found to increase the early age compressive strength and long term corrosion resisting characteristics of concrete. High volume fly ash can be used to produce high quality pavements in concrete (Siddique R. 2004). Low calcium fly ash can be produced by burning anthracite or bituminous coal and high calcium fly ash can be produced by burning lignite or bituminous coal.

Fly ash concrete mixes can be divided into three categories. Simple replacement method involves direct weight replacement of a part of Portland cement with fly ash with an adjustment for yield of concrete. Addition method involves addition of fly ash to cement replacing partial aggregate in concrete to achieve yield of concrete. Third method is divided in two as modified replacement and rational proportioning method. In the modified replacement method fly ash content is modified to compare the properties with parent concrete. Rational proportioning method has a binding efficiency factor k, with weight of fly ash equivalent to cement having a weight Kf.

Figures 2-16 and 2-17 show the fly ash and bottom ash production and use statistics in the last 15 years. As you can see, the fly ash production has been declining since 2010, but the use of fly ash has remained constant over the years. Hence, the fly ash used as a percent of produced has significantly risen to more than 50%. By this rate, the fly ash production and consumption will end up being equal and eventually will lead to a shortage of supply. Similarly, the bottom ash consumption has remained constant while the production has reduced. Although, this is not as alarming as that of fly ash but eventually it will lead to a similar situation. Figure 2-18 shows all the production and use statistic of all coal combustion products in the United States in the last 25 years. The combustion products usage has gradually increased from 25% in 1991 to almost 55% in 2015 which is a combination of decrease in production as well as increase in the use.

Element	Bituminous	Sub-Bituminous	Lignite
SiO_2 (%)	20-60	40-60	15-45
Al_2O_3 (%)	5-35%	20-30	10-25%
Fe_2O_3 (%)	10-40%	4-17%	4-15%
CaO (%)	1-17%	5-17%	15-40
MgO (%)	0-5	1-6%	3-10%
SO_2(%)	0-4	0-2	0-15
Na_2O (%)	0-4	0-2	0-6
K_20 (%)	0-3	0-4	0-4
LOI (%)	0-15	0-3	0-5

Figure 2-14. Typical range of elemental composition for Coal Combustion Products from different coals, wt% (Heidrich et al., 2013)

Requirement	**Class F**	**Class C**
(SiO_2 + Al_2O_3 + Fe_2O_3), min %	70.0	50.0
Loss on Ignition (LOI), max %	6.0*	6.0
Fineness, retained on 45 µm (No. 325) sieve, max %	34	34
*ASTM C618 permits up to 12% LOI with documented service records or laboratory evaluation.		

Figure 2-15. Fly ash requirements per ASTM standards (adopted from NRMCA specification.)

Fly Ash Production and Use with Percent

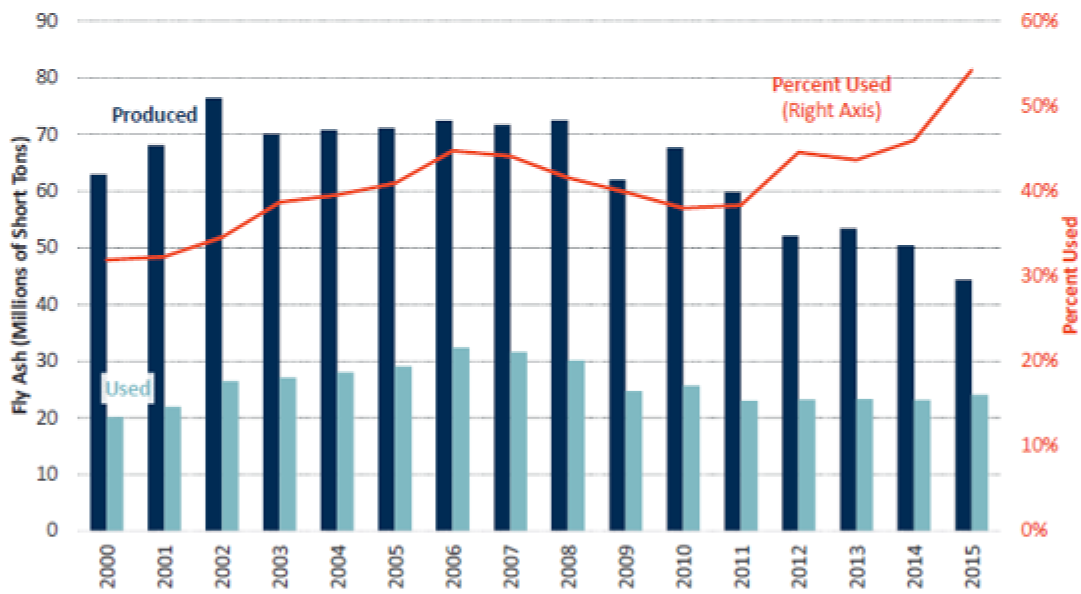


Figure 2-16. The fly ash production and use statistics (adopted from American Coal Ash Association)

Bottom Ash Production and Use with Percent

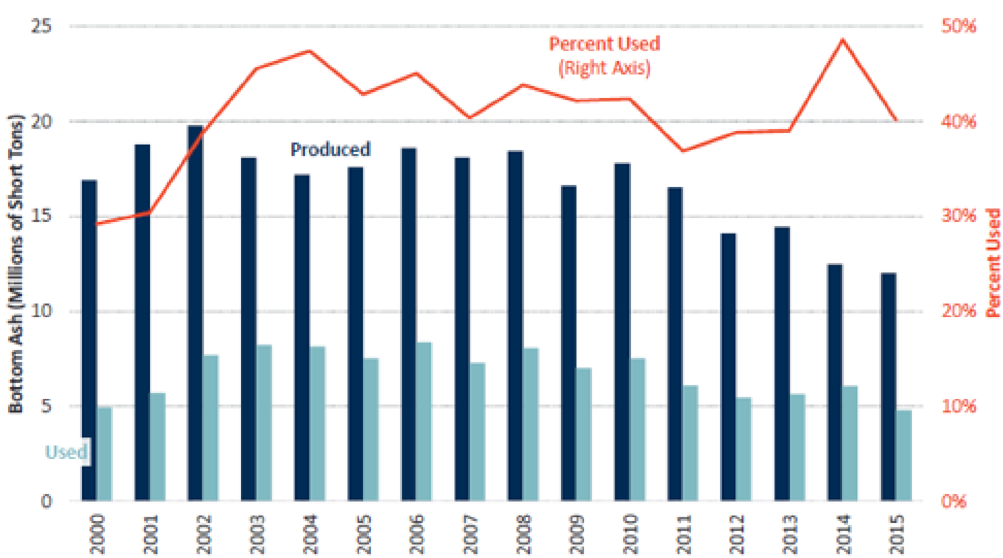


Figure 2-17. The bottom ash production and use statistic in the last 15 years (adopted from American Coal Ash Association)

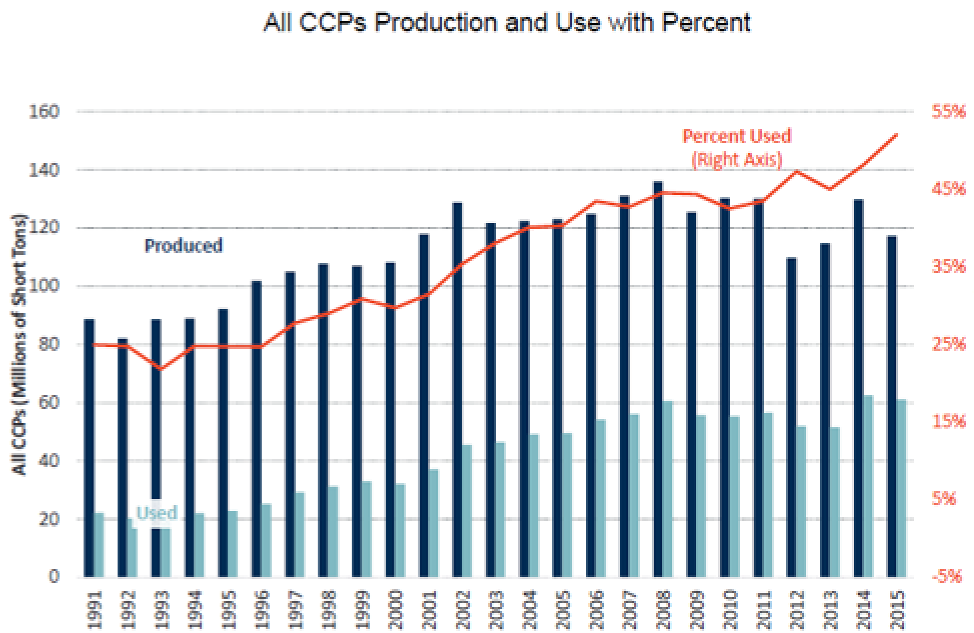


Figure 2-18. All the Coal Combustion Products produced and used in 25 years (adopted from American Coal Ash Association)

2.5 Wood Ash

Wood ash is the residue generated due to the combustion of wood and its products like chips, saw dust bark etc. Wood ash is a byproduct generated from the combustion in boilers at pulp mills, steam power plants and other thermal power generating facilities. The major problem of using timber waste product as a fuel is the generation of ash. Hardwood is observed to produce more ash than softwood while the bark and inner leaves produce more ash as compared to the inner part. Characteristics of the collected wood ash depend on the type of wood, the combustion process and the location of ash collection. Wood ash may be a cause of health hazard if it gets air borne with the wind. These health hazards include respiratory problems and irritation to people dwelling near the site. (Sebastian A. et al. 2016). Therefore, care needs to be taken to avoid such problems. Wood ash is an important agricultural waste. As it is a renewable source for energy and an environmentally friendly material, it can be used for energy production. Therefore, there is large amount of wood waste ash generated and available to be used for different purposes. Almost 70% of the wood waste is deposited in the environment in different forms (Aprianti E. et al. 2015). Biomass which consists of forestry and agricultural wastes is a considerable source of renewable energy. Landfilling is the most prevalent method accounting for 70% of the ash generated from wood combustion, 20% wood ash is used as soil supplement while the rest is used on miscellaneous jobs. The characteristics of this wood ash depend on herbaceous material, wood or bark (Chowdhury S. et al. 2015). The physical and chemical properties of wood ash depend on the species of wood, the combustion temperature, efficiency of the boiler and supplementary fuels used. Ash content yield decreases with increase in temperature of combustion. Etiegni (1990) obtained X-ray diffraction data to determine the different oxides like lime, calcite, portlandite and calcium silicate present in wood ash. Wood ash contains fine particulate matter which can become airborne after combustion, causing respiratory disorders. It is therefore, important to treat the wood ash properly. The use of wood ash in concrete can reduce the disposal problems and reduce the cost of concrete. High carbon content has limited the use of wood in low and medium strength concrete materials. Etiegni (1990) also studied the effect of combustion temperature on yield and chemical properties. Naik et al. (2003) studied the chemical composition of different types of wood ash and found that some of them did not meet ASTM C 618 criteria. Chowdhury et al. (2015) studied the compressive, flexural and tensile strengths of concrete with different percentages (5%, 10%, 15%, 18% and 20%) of blended Wood Ash cement. They observed that these strengths decreased marginally with increase in wood ash contents but recovered at later ages.

Subramaniam P et al. (2015) studied the use of wood ash as a partial replacement to cement for manufacturing concrete blocks. They observed that the compressive strengths of blocks with 20% wood ash replacement was comparable with the control specimen. The optimum wood ash replacement percent that gave the best results was found to be 15%. (Sashidhar C. and Rao H. 2010) also studied the effects of replacement of cement with wood ash. They observed that H_2SO_4 attack on wood ash is severe as it resulted in a decrease in strength of concrete. 10% wood ash replacement had the minimum acid attack. The water absorption capacity was found to decrease with increase in wood ash content from 0 to 30%.

2.6 Literature Review Summary

Literature review covered the issues of global warming emissions associated with increasing population. It also covered the increasing demand of cement consumption and the carbon dioxide emissions associated with it. Literature included the different types of supplementary cementitious materials used in concrete like fly ash, corn ash and wood ash. From the literature, it was observed that there is extensive research on the use of corn ash and wood ash in countries like Nigeria and India. The literature has covered the study of compressive and tensile strengths, workability, slump, bulk density and specific gravity of concrete having corn and wood ash. Further tests to check the Aluminum, Silica, Magnesium, Iron, Sulphur and Potassium percentages in corn and wood ash have also been demonstrated.

CHAPTER 3
METHODOLOGY

3.1 Physical and Chemical Property Comparison

The physical and chemical properties of wood ash and corn ash were obtained from the literature. Research included studying articles that focused on using wood ash and corn ash in concrete.

3.1.1 Properties of wood and corn ash

Physical properties including pH, moisture content, bulk density and specific gravity are individual properties of wood ash, corn ash and fly ash. Individual fly ash properties were obtained from the U.S. Department of Transportation report on coal fly ash. Chemical properties including silicon, aluminum, iron, calcium, potassium and sodium oxide percentages are individual properties of wood ash, corn ash and fly ash.

3.1.2 Properties of concrete made with wood and corn ash

Physical properties including compressive strength, initial setting time, final setting time, soundness and slump were considered for concrete containing wood ash, corn ash and fly ash. For example: compressive strength of wood ash was considered for concrete containing 15% wood ash. Properties including compressive strength, initial setting time, final setting time, soundness and slump for concrete containing fly ash were obtained from the PCA manual - Chapter 3.

3.2 Ideal Replacement Percentage of Wood and Corn Ash

The ideal replacement percentages of wood ash and corn ash to achieve 3000 psi concrete was obtained from the literature. The reason for choosing 3000 psi concrete was that the scope of the study involved wood ash and corn ash availability to use in low-strength concrete. Studies were reviewed that tested the compressive strength of wood ash concrete and corn ash concrete. The tests involved concrete samples with incremental percentages of wood ash or corn ash. The results of the compressive strength tests of corn ash and wood ash used in concrete can be seen in figures 4-1 and 4-2 respectively.

3.3 Cement Consumption for Low Strength Concrete

The scope of the study involved the calculation of the ash requirement for low-strength concrete in Florida (less than 3500 psi). To calculate the ash requirement, it was necessary to find the annual cement consumption in Florida. This was obtained from the Portland Cement Association (PCA'16). This association represents 92% of cement manufacturing in the United States. The average cement consumption from 2003-2016 was calculated to obtain more accurate results. The cement consumption was further narrowed to that used in ready-mix concrete production. This was obtained from the 2016 data on cement used by a user group (Statista). As the scope of study involved low-strength concrete, it was necessary to find the annual cement consumption for low-strength concrete in Florida. Per a report from the National Ready-Mix Concrete Association (NRMCA), it was observed that 64% of the total concrete production in the south-east United States consisted of concrete below 3500 psi strength. Therefore, the annual cement consumption for low-strength concrete was calculated as 64% of the total cement consumption used for ready-mix concrete in Florida.

3.4 Wood Ash Requirement and Availability

The wood ash requirement was calculated by using the wood ash replacement percentage and the annual cement consumption determined in 3.1 and 3.2 respectively. By knowing the wood ash replacement percentage and the annual cement consumption, it was possible to determine the annual wood ash quantity that would be required for low-strength concrete in Florida.

The calculation of wood ash availability was based on the annual generation of solid wood waste in Florida. These data were obtained from the Florida Department of Environmental Protection which had the annual solid waste statistics. Solid waste consists of wood waste, yard trimmings etc. It was observed that wood waste and yard trimmings consist of 20% of the total solid waste collected annually (MSW). Therefore, the total quantity of wood waste that can potentially be used in biomass plants was determined. It has been reported that 1 t of municipal solid waste generates 481 kWh of electricity (EIA). However, the biomass materials burned in the biomass plants accounted for 64% of the weight of the MSW and contributed approximately 51% of the energy. Therefore, the amount of electricity generated by 1 t of biomass was determined. Different biomass plants were studied to find the quantity of wood ash generated as a function of the power generation capacity of the biomass plant. However, none of the biomass plants could provide wood ash generation statistics. Therefore, a conservative estimate of 4% ash generation from the biomass plant was assumed to determine the potential quantity of wood ash that would be generated from the biomass plants.

3.5 Corn Ash Requirement and Availability

As for wood ash, the annual corn ash requirement for low-strength concrete was calculated by using the corn ash replacement percentage and the annual cement consumption determined in 3.1 and 3.2.

To calculate the annual corn ash availability, the corn generation statistics of Florida were studied. The annual production of corn in Florida was determined from the

United States Department of Agriculture. The amount of ash generation depends on the quantity of corn stover left after harvest. This corn stover consists of bales, stalks, leaves and cob. The amount of corn stover generated per acre was obtained from a feasibility study conducted in the Midwest (Corn Report). After determining the quantity of corn stover generated in Florida, it was necessary to determine the ash that can be generated from the corn stover. The ash generation for corn cob, husk, leaves and stalk was studied (Lizotte P et al. 2015). The average ash generation percentages of corn cob, husk, leaves and stalk was taken to calculate the potential corn ash generated from corn stover in Florida.

3.6 Environmental Impacts

The environmental impacts of wood ash include only the energy required for transporting ash to the concrete gate. As wood ash is a byproduct of biomass plants, there is no processing energy or non-energy emissions associated. Corn stover is currently not used as a raw material in biomass plant. However, the potential of using it in biomass plants is significant. To calculate the environmental impacts, it was assumed that corn stover is used as a raw material in biomass plants. Therefore, its environmental impacts include transportation energy emissions such as wood ash. The environmental impacts of fly ash consist of the transportation energy emissions. The distance of all waste materials was calculated from their respective power plants. To obtain accurate results, it was decided to calculate the environmental impacts in two locations. Orlando was chosen as one because of its central location in Florida. Miami was selected as the second location because of the increasing construction activity under way in south Florida (Biz). Sources of all materials near Orlando and Miami were searched. The source of fly ash was taken as the C.D McIntosh Power Plant in

Lakeland, FL. The wood ash source was the Gainesville Renewable Energy Center biomass plant in Gainesville, FL. The corn ash source selected was the I.H.I. Power Service, in Brooksville, FL. Similarly, the sources of corn ash, wood ash and fly ash near Miami were determined. Environmental impacts of wood and corn ash were compared with those of fly ash. The transportation energy unit to measure the environmental impacts was chosen as metric tons of carbon equivalent per ton of material.

3.7 Cost

The cost of all materials was obtained from industry sources. The cost of fly ash was taken from the Florida Department of Transportation website. The cost of corn stover was found to vary depending on the supply and demand characteristics. Due to limitations in availability of sources in Florida, the cost of corn stover was taken from sources in the Midwest region. This cost was found to be in the range of $40-80/ton depending on the location and availability (Purdue). The high range of price was because of the reimbursement cost applied by the corn producers for the nutrients removed with the stover. To obtain a better cost estimate of corn stover, a 10% markup was applied due to its limited availability in Florida. The cost of wood ash per ton was obtained from an article in Wisconsin.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Corn Ash Analysis

4.1.1 Physical Properties of Corn Ash

Physical properties including specific gravity, pH, moisture content and bulk density are individual properties of corn ash. These were compared with individual properties of fly ash. The moisture content of corn ash was found to vary depending on the type of combustion process as well as the percentage of corn cob, leaves and stalks burnt in the biomass plants. The specific gravity and bulk density of corn ash was in the same range as that of fly ash which suggested that the mass to volume ratio of corn ash and fly ash was same.

4.1.2 Physical Properties of Concrete Made with Corn Ash

This section analyzes the physical properties of concrete made with corn ash found in the literature with those of Portland cement concrete having fly ash. These properties included soundness, initial setting time, final setting time, slump and compressive strength. It was observed in figure 4-1, that the initial and final setting time of concrete made with corn ash, increased from 30 to 208 min and 200 to 328 min respectively. This was because of the reduction in surface area of cement due to increase in corn ash percentages that slowed the hydration process. The slow hydration process reduced the thermal stresses due to the low rate of heat development. Per figure 4-1, the 28-day compressive strength of concrete with corn ash was observed to decrease with increasing corn ash percentages. The 28-day strength of concrete (2900 psi) with 10% corn ash replacement, just managed to meet the minimum requirement. The strength increase was slow because of the lower percentage of highly reactive silica reducing the rate of hydration. The slump of corn ash concrete was like that of normal concrete suggesting that the corn ash does not affect the workability of concrete.

4.1.3 Chemical Properties of Corn Ash

Chemical property comparison consisted of the individual properties of corn ash and fly ash. ASTM C 618 requires fly ash to have more than 70% silica, alumina and calcium content to be a good pozzolan. The American Concrete Institute code (ACI), 318-08 chapter 4 defined the maximum percentage of fly ash to be used in concrete depending on the type of construction. As there was no separate specification for corn ash, it was compared with ASTM C 618 requirements which specify the use of fly ash in concrete. It was observed in figure 4-2, that the combined percentage of silica (SiO_2), alumina (Al_2O_3) and calcium oxide (CaO) was more than 70%, which was an indication of good pozzolan. These compounds were responsible for the formation of calcium aluminum hydrates when reacting in the presence of calcium hydroxide and water. Thus, as the percentage of corn ash increased, more silica and alumina content became available for reacting with calcium hydroxide. The Loss of ignition (LOI) value requirement for OPC was a maximum of 6 under ASTM C 618. It was observed that the LOI value for corn ash was high, indicating a higher mass-change.

4.2 Wood Ash Analysis

The literature showed that chemical and physical properties of wood ash depend on the type of wood used and the type of combustion process. Wood waste generally consists of sawdust, chips and bark which have different combustion properties. Wood ash is a byproduct of the biomass plants that use wood waste to generate electricity. Just like coal fly ash, wood ash is also differentiated as wood fly ash and bottom ash.

4.2.1 Physical Properties of Wood Ash

Physical properties including specific gravity, pH, moisture content and bulk density are individual properties of wood ash. These were compared with the individual properties of fly ash. The pH was found to vary between 9 and 13.5 indicating varying levels of alkalinity. The range of specific gravity values (0.16-1.4) was due to the varying percentages of chips, sawdust and bark in the wood waste. The moisture content of wood ash was very low compared to fly ash. To produce high quality cement based products incorporating wood ash, not only must the moisture content be kept low but the variability in moisture content must be minimized. Low moisture content in wood ash would also reduce the transportation cost to the concrete gate.

4.2.2 Physical Properties of Concrete Made with Wood Ash

Just like corn ash, this section analyzes the physical properties of concrete made with wood ash found in the literature with those of Portland cement concrete having fly ash. These properties included soundness, initial setting time, final setting time, slump and compressive strength. The initial and final setting time values of concrete made with wood ash were higher than those of concrete containing fly ash. The slump value of concrete containing wood ash was observed to be very low indicating less workable concrete. This indicated that more water would be required to increase the workability.

4.2.3 Chemical Properties of Wood Ash

Just like corn ash, the chemical property comparison involved the comparison of individual properties of wood ash and fly ash. The minimum 70% requirement of silicon dioxide, aluminum oxide and iron oxide fell short, the combined percentage equaled 63%. Wood ash was observed to swell because of hydration of silicates and the lime present in the ash. The loss on ignition was found to be 31.6% which is significantly high than the maximum of 6% required for pozzolan per ASTM C618 specification. This was because of the substantial amount of unburnt carbon present in wood ash. The alkali content (Na_2O) was found to be higher (6.5%) than the maximum required (1.5%).

Properties	Wood Ash	Corn Ash	Fly Ash
Specific Gravity	0.16- 1.4	1.15	0.9-1.3
Ph	9-13	6	8-10
Moisture Content	2.60%	20%	18-38%
Bulk Density	10.1-85.6 lbs/ft^3	$72 lb/ft^3$	56-81 lbs/ft^3

Figure 4-1. Comparison of physical properties of wood ash, corn ash and fly ash.

Properties	Wood Ash (15% replacement)	Corn Ash (10% replacement)	Fly Ash (20%)
Initial Setting Time	135min	208min	30 mins
Final Setting Time	283min	328min	200min
Slump	2.5mm	28.5mm	10-30mm
Compressive Strength (28-day)	3150 psi	2900 psi	4785 psi
Soundness	1.10mm	3.00mm	10mm

Figure 4-2. Comparison of physical properties of concrete made with wood ash, corn ash and fly ash.

No.	Chemical Properties%	Wood Ash	Corn Ash	Fly Ash
1	Silicon Dioxide	50.70%	22.15%	38-63%
2	Aluminum Dioxide	8.20%	4.51%	27-44%
3	Iron Oxide	9.80%	3.94%	3.3-6.4%
4	Calcium Oxide	3.50%	62.18%	0.2-8%
5	Magnesium Oxide	0.70%	2.47%	0.01-0.5%
6	Potassium Oxide	1.10%	0.76%	0.04-0.9%
7	Sodium Oxide	0.90%	0.35%	0.07-0.43%
8	LOI	31.60%	21.44%	0.2-5.0%

Figure 4-3. Comparison of chemical properties of wood ash, corn ash and fly ash.

Figure 4-3 provides the compressive strength test results for different percentage replacements of cement with wood ash. The 28-day strength for 15% replacement is 3150 psi indicating that for 3000 psi concrete, a maximum of 15% cement can be replaced with wood ash. It was observed that there was a significant gain in strength at a later age due to the slow pozzolan activity of wood ash.

Wood Ash Replacement (%)	Compressive strength (psi)	Compressive strength (psi)	Compressive strength (psi)
	7 days	14 days	28 days
0	2443	3393	4110
5	2219	2656	3568
10	2219	2453	3169
15	2056	2288	**3150**

Figure 4-4. 7, 14 and 28-day compressive strengths of 3000psi concrete with different percentage of wood ash. (adopted from Udoeyo F et al. 2006).

Figure 4-4 provides the different compressive strength test results for different percentage replacements of cement with corn ash in concrete. The 28-day strength for 10% replacement is 2900 psi indicating that for 3000 psi concrete, a maximum of 10% cement can be replaced with corn ash.

Corn Ash Replacement (%)	Compressive strength (psi)	Compressive strength (psi	Compressive strength (psi
	7 days	21 days	28 days
0	2127	3050	3580
10	1911	2814	**2900**
20	1331	1847	1998

Figure 4-5. 7, 21 and 28 day compressive strengths of 3000 psi concrete with different percentage of corn ash. (adopted from Oladipupo O. and Festus O. 2012).

According to the literature, concrete with 3000 psi strength, had a maximum of 15% wood ash replacement levels. Increasing the wood ash percentage beyond 15% was observed to reduce the strength of concrete mixes. Therefore, the replacement percentage of cement with wood ash that could achieve 3000 psi strength concrete was chosen to be 15%. Similarly, for corn ash, according to the literature, concrete with 3000 psi strength, had a maximum replacement level of 10%. Increasing the corn ash percentage beyond 10% was observed to achieve less than 3000 psi strength. Therefore, replacement percentage of cement with corn ash that could achieve 3000 psi strength concrete was chosen to be 10%. The fly ash replacement level of 20% was chosen from the FDOT for low-strength concrete mixes.

4.3 Cement Consumption Analysis

The annual cement consumption of 6 million tons in Florida was obtained from the PCA for 2016 (PCA). To obtain accurate results, the average cement consumption from 2003-2016 was calculated. Figure 4-6 shows the average cement consumption from 2003-2016. This included the average of 14 years which was equal to 4.8 million tons. Cement consumption for ready-mix concrete composed 70% of the total cement consumption in the United States. Therefore, the annual cement consumption for ready-mix concrete was calculated as 3.36 million t. The scope of this study was restricted to cement consumption for concrete with less than 3500 psi strength. Per NRMCA data, 64% of the total concrete consumption in the south-east region of United States had less than 3500 psi strength. Therefore, the annual cement consumption for low-strength concrete was calculated to be 2.15 million t.

Years	Cement Consumption (million tons)
2003	4.2
2004	5.3
2005	5.8
2006	5.8
2007	5.7
2008	5.4
2009	3.2
2010	3.2
2011	3.4
2012	3.9
2013	4.9
2014	5.1
2015	5.5
2016	6
Average	4.8

Figure 4-6. Average Cement Consumption from 2003-2016

4.4 Wood Ash Demand and Supply Analysis

The wood ash percentage obtained from 3.1 was used to calculate the wood ash requirement for use in low-strength concrete. Thus, the annual wood ash demand in Florida was determined as 322,500 t by replacing 15% of the annual cement consumption determined in 4.3.

Per the Florida Department of Environmental Protection, nearly 14.8 million tons of solid waste is landfilled annually (Solid Waste in Florida). From the literature, it was observed that 20% of the total solid waste is composed of wood and yard trimmings (MSW). Therefore, Florida has approximately 3 million t of wood waste that is landfilled annually. Per the EIA, 1 t of MSW generates 481kWh of electricity. However, the biomass materials in the MSW that burn in the power plants account for 64% of the weight of MSW and contribute to 51% of the energy. Therefore, 1 t of biomass generates 383kWh of electricity. Therefore, 3 million t of wood waste has a potential of generating 1,149 GWh electricity. The annual electricity consumption in Florida is 17,300 GWh (U.S EIA). Thus, there is a 7% potential of total electricity generation using biomass plants. Assuming a conservative 4% ash generation from the biomass plant, the potential quantity of wood ash available in Florida is 120,000 t.

From Table 4-2, 37% of the annual wood ash requirement can be covered by the potential wood ash generated in Florida.

4.5 Corn Ash Demand and Supply Analysis

Just like wood ash, the corn ash replacement percentage obtained from 3.1 was used to determine the annual corn ash requirement. Thus, the annual corn ash demand in Florida was determined as 215,000 t by replacing 10% of the annual cement consumption obtained in 4.3.

To calculate the annual corn ash availability, the corn generation statistics in Florida were studied. Per United States Department of Agriculture, Florida has 40,000 acres of corn production. With 145bu/acre, there is a total 5,800,000 bu. of annual corn production in Florida (USDA). The amount of ash generation depends on the quantity of corn stover remaining after harvest. This corn stover consists of bales, stalks, leaves and cob. One hundred forty-five bushels of corn produce 3.3 dry tons of corn stover per acre (Corn Report). Therefore, the total quantity of corn stover generated annually in Florida was 132,000 t. The ash generation for corn cob, husk, leaves and stalk was studied and the average was taken as 5% (Lizotte P et al. 2015). Thus, the potential corn ash generation in Florida was 6,600 t which is 3% of the annual requirement.

The potential wood ash supply is 37% of the annual requirement. Wood ash can be considered for use as a partial replacement of fly ash in low-strength concrete. However, with the increase in solid waste generation per year, more wood waste is being landfilled. If such waste is used in biomass plants to generate renewable energy, more wood ash will be generated. It will also help reduce the electricity generated from coal combustion, which will help reduce carbon emissions. Renewable electricity generation through biomass has evolved over the years. Electricity generation in biomass plants involves different combustion technologies including fixed bed, fluidized bed and pulverized bed (James A et al. 2012). Fluidized bed technology is considered the best to burn low quality fuel, obtain high ash content and generate low calorific value (Saidur R. et al. 2011). Therefore, the use of biomass plants is also increasing with better techniques for electricity generation. Using wood ash in concrete, will also help reduce the disposal problems of ash generated from these biomass plants. Florida has 18 biomass plants, among the most in the United States (Biomass). Four of these plants use wood biomass as the main raw material. Therefore, the scope of generating wood ash is increasing every year. The following is a list of the biomass plants running on wood waste in Florida:

1. Brooksville- IHI Power Services: 70MW
2. Gainesville Renewable Energy Center: 102.5MW
3. Multitrade Telogia: 14MW
4. Telogia Power: 14MW

Corn ash availability is very low in Florida with only 5,800,000 bu. harvested annually. The potential corn ash supply is 3% of the annual requirement making it unfavorable for use. Currently, the primary use of corn stover is as a biofuel in ethanol production. It is also used as a feedstock and as bedding for cattle. According to the Department of Energy, corn stover is expected to be the dominant source for renewable energy generation compared to all other sources of biomass (Corn Harvest). With increasing levels of corn production, the quantity of corn stover generated will increase in future years. Therefore, the potential of using corn stover in biomass is significant which will increase the quantity of ash generated. Most of this corn production is however from the Midwest region. Therefore, there would be the additional cost of transporting the ash to Florida.

Table 4-1. Replacement percentages of wood ash, corn ash and fly ash.

No	Waste Material	Percentage Replacement
1	Wood Ash	15%
2	Corn Ash	10%
3	Fly Ash	20%

Table 4-2. Calculations of wood ash requirement and availability.

1	Total Cement production in Florida	4.8 million t
2	Cement consumption for ready-mix concrete production (70%)	3.36 million t
3	Cement consumption for low-strength concrete (64%)	2.15 million t
4	Wood ash required (15% replacement)	322,500 t
5	Wood waste landfilled in Florida	3 million t
6	Ash availability (4% ash generation)	120,000 t

Table 4-3. Calculation of corn ash requirement and availability.

1	Total cement production in Florida	4.8 million t
2	Cement consumption for ready-mix concrete production (70%)	3.36 million t
3	Cement consumption for low-strength concrete (64%)	2.15 million t
3	Corn ash requirement (10%)	215,000 t
4	Corn production	5,800,000 bu.
5	Corn stover	132,000 t
5	Corn ash availability (5% ash generation)	6,600 t

4.6 Environmental Impacts

The environmental impacts of all materials were calculated by comparing the difference in greenhouse gas emissions associated with transporting 1 t of fly ash, wood ash and corn ash to the concrete plant gate. As all materials under consideration are byproducts, the processing energy associated with acquiring the materials was taken as zero. Therefore, the greenhouse gas emissions consist of only the transportation energy emissions. These emissions were from the combustion of fossil fuels required to transport the material to the concrete gate. Transportation energy was measured in metric tons of carbon equivalent per ton of material transported. Therefore, the sources of cement, fly ash, blast furnace slag, wood ash and corn ash nearest to Orlando were selected. The source of wood ash was the biomass plant in Gainesville, FL. The source of fly ash was the coal combustion plant in Lakeland, FL. Currently, corn ash is not produced in the United States. It was assumed that the corn waste was used in biomass plants to generate corn ash as a byproduct. Therefore, the source of corn ash was taken as the IHI Power Services Corporation biomass plant in Brooksville, FL. Figure 4-7 lists all the suppliers and their distance to Orlando. Similarly, Figure 4-8 lists the sources of corn ash, fly ash and wood ash near Miami. Google Maps was used for calculating the distance. The fuel used for transport was taken as diesel. The transportation combustion energy factor for each material in Figure 4-9 was the product of the combustion factor of diesel and the distance travelled. The combustion energy coefficient for diesel was obtained from the US EPA document of life-cycle greenhouse emissions (EPA). Figures 4-9 through 4-12 discuss the transportation energy per ton for fly ash, wood ash and corn ash in both Orlando and Miami.

Material	Supplier	Distance to Orlando (miles)
Fly Ash	C.D McIntosh Power Plant, Lakeland	55
Wood Ash	Gainesville Renewable Energy Center	113
Corn Ash	IHI Power Services Corporation	80

Figure 4-7. List of all material suppliers near Orlando.

Material	Supplier	Distance to Miami (miles)
Fly Ash	Indiantown Cogen Power Station	104
Wood Ash	Wheelabrator Technologies, Inc.	43
Corn Ash	Palm Beach Renewable Energy	80

Figure 4-8. List of all material suppliers near Miami

Material	Transportation Combustion Energy, Diesel Fuel (million Btu/ton-mile)	Transportation Distance to Orlando (miles)	Transportation Combustion Energy (million Btu/ton)	Transportation Distance to Miami (miles)	Transportation Combustion Energy (million Btu/ton)
	(a)	(b)	(c= a x b)	(d)	(e= a x d)
Fly Ash	0.0015	55	0.0825	104	0.16
Wood Ash	0.0015	113	0.1695	43	0.06
Corn Ash	0.0015	80	0.12	80	0.12

Figure 4-9. Combustion energy coefficients in mBtu/t

Transport energy emissions were calculated based on the energy spent in the combustion of fossil fuels to transport the fly ash to the concrete gate. The fuel specific carbon coefficient and CH_4 emissions were taken from the EPA document. Based on the combustion coefficient of diesel and distance traveled, the transport energy emissions of CO_2 and CH_4 were calculated to obtain the total transportation greenhouse gas emissions.

Concrete Gate Location	Percent of Total Btu	Million Btu used for Fly Ash transport	Fuel Specific Carbon Coefficient (MTCE/Million Btu)	CH_4 emissions (MTCE/Million Btu)	Transport Energy CO_2 emissions (MTCE/Ton)	Transport Energy CH_4 emissions (MTCE/Ton)	Total Transport Energy Emissions (MTCE/Ton)
	(a)	(b)	(c)	(d)	(e= b x c)	(f= b x d)	(g= e + f)
Orlando	100	0.0825	0.0199	0.0001	0.0016	0.000008	0.0016
Miami	100	0.16	0.0199	0.0001	0.003184	0.000016	0.0032

Figure 4-10. Transportation energy emissions for 1 t of fly ash

Wood ash is a byproduct of electricity generation in biomass plants. Just like fly ash, fuel-specific carbon and CH_4 emission coefficients are obtained from the EPA document. These coefficients are multiplied by the transportation energy combustion coefficients in Figure 4-8 to obtain CO_2 and CH_4 emissions for wood ash.

Concrete Gate Location	Percent of Total Btu (a)	Million Btu used for Wood Ash transport (b)	Fuel Specific Carbon Coefficient (MTCE/Million Btu) (c)	CH_4 emissions (MTCE/Million Btu) (d)	Transport Energy CO_2 emissions (MTCE/Ton) (e= b x c)	Transport Energy CH_4 emissions (MTCE/Ton) (f= b x d)	Total Transport Energy Emissions (MTCE/Ton) (g= e + f)
Orlando	100	0.1695	0.0199	0.0001	0.003373	0.000016	0.0034
Miami	100	0.06	0.0199	0.0001	0.001194	0.000006	0.0012

Figure 4-11. Transportation energy emissions for 1 t of wood ash

Currently, corn stover is not used as a raw material for electricity generation in biomass plants. Its primary use is in ethanol production as a biofuel. However, the hypothesis was that the corn stover can be used as a raw material in biomass plants for electricity generation. The corn ash generated can be used in concrete. The chemical composition of corn stover involves nitrogen, calcium and potassium oxide in major proportions. The transportation energy calculation for corn ash involved similar calculations to those of wood ash. Biomass plants near Orlando and Miami were searched for the source of corn ash. The distance of these biomass plants to Orlando and Miami was used to calculate the transportation energy emissions. Therefore, the transportation energy emission of corn ash was calculated like wood ash.

Concrete Gate Location	Percent of Total Btu (a)	Million Btu used for Corn Ash transport (b)	Fuel Specific Carbon Coefficient (MTCE/Million Btu) (c)	CH_4 emissions (MTCE/Million Btu) (d)	Transport Energy CO_2 emissions (MTCE/Ton) (e= b x c)	Transport Energy CH_4 emissions (MTCE/Ton) (f= b x d)	Total Transport Energy Emissions (MTCE/Ton) (g= e + f)
Orlando	100	0.12	0.0199	0.0001	0.0024	0.000012	0.0024
Miami	100	0.12	0.0199	0.0001	0.0024	0.000012	0.0024

Figure 4-12. Transportation energy emissions for 1 t of corn ash

After calculating the transportation energy emissions of fly ash, wood ash and corn ash, it was observed in Figures 4-10 through 4-12, that the transportation energy emissions due to CH_4 are negligible as compared to CO_2 emissions. Therefore, neglecting CH_4 emissions, the total greenhouse gas emissions consist of CO_2 emissions. Transportation emissions for corn ash were lower than wood ash in Orlando but higher in Miami. Fly ash had the lowest greenhouse gas emissions in Orlando but the highest emissions in Miami. This was because of the proximity of the fly ash source to Orlando. With the current availability of wood and corn ash, the transportation energy values were higher than fly ash in Orlando. In contrast, due to the proximity of biomass plants near Miami, the transportation energy values of wood ash and corn ash were lower than those of fly ash. However, if the recent trend in the reduction in fly ash generation continues, the sources of fly ash may become limited. In that scenario, wood and corn ash can be considered as possible replacement options. With upcoming biomass plants in Florida, it would be possible to reduce the transportation distances and the energy emissions associated with them.

Table 4-4. Transportation Energy Emissions in MTCE/t

Material	Transportation energy emissions travelling to Orlando (MTCE/t)	Transportation energy emissions travelling to Miami (MTCE/t)
Fly Ash	0.0016	0.0032
Corn Ash	0.0024	0.0024
Wood Ash	0.0034	0.0012

4.7 Cost

The availability and cost play an important role when evaluating the feasibility of using any materials. The cement industry is affected by regulatory norms because of strict environmental issues. The average price of cement in the United States is $130/t

(Statista). The reason for the high cement price is the processing energy and raw materials spent in manufacturing cement. Cement prices also depend on the current economic situation.

Fly ash prices have been steady over the years. However, recent closure of coal plants, has resulted in a decrease in fly ash production. The cost of fly ash was $35/t (FDOT). The American Road & Transportation Builders Association report predicted the utilization of fly ash to grow by 2.2% per year. However, the production of fly ash, is projected to grow at only 0.1% per year. The fly ash utilization rate was 45% in the United States in 2013 which is predicted to increase to 63% by 2033 (ACAA). This difference in production and demand may create availability problems in the future. A reduction in availability may lead to increased fly ash prices.

Wood ash is generated in biomass plants when wood waste is burned to produce renewable energy. The cost of wood ash was taken as $24-38/t. (Kopecky M et al. 2013)

Currently, corn ash is not used as a raw material in biomass plants. Therefore, the cost of corn ash was not available. The cost of corn stover in Florida was not available because of limited availability. Therefore, the cost of corn stover from the Midwest was taken for reference. To get a better estimate of price in Florida, a 10% increase was considered to offset the increase in price due to reduction in availability. Therefore, the cost of corn stover was $45-75/t.

Table 4-5. All materials and their costs

Material	Cost per Ton
Cement	\$130
Fly Ash	\$35
Wood Ash	\$24-38
Corn Stover	\$45-75

The current market cost of wood ash is comparable to fly ash. Therefore, it can be used without affecting the current cost of concrete. The cost of corn stover is found to vary depending on location and market condition. Due to limited availability, this cost is bound to be on the higher side. Using corn stover to replace fly ash will increase the cost per ton of concrete. In the absence of fly ash, for cement with blast furnace slag, the cost per ton of concrete becomes the highest. In that situation, using corn stover, will help reduce the cost of concrete. In addition, using wood ash and corn ash in concrete will reduce the cost of dumping the ash in landfills. The average cost of waste disposal prices of \$30/t charged by landfill sites or yard trash will help save \$3.6 million because of the 120,000 t of wood ash generated annually in Florida. (DEP).

CHAPTER 5
CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The following were the key findings of the thesis:

1. The physical properties of wood ash and corn ash included their individual properties as well as the properties of concrete made with wood ash and corn ash. Individual properties including moisture content, specific gravity and bulk density were compared with those of fly ash. The chemical properties of wood ash and corn ash including silica, aluminum, calcium and magnesium were compared with those of fly ash. It was observed from the literature that the silica, aluminum and calcium contents of wood and corn ash satisfy the ASTM C 618 requirements for a pozzolan.

2. The physical properties of concrete containing wood ash or corn ash were compared with concrete containing fly ash. These properties included the initial and final setting times, slump and compressive strength. The initial and final setting times of concrete with wood or corn ash are higher than those made with concrete having fly ash because of slow reactive alkalis. This also resulted in slow gain in the compressive and tensile strength of concrete. Based on the properties studied, it was observed that wood ash and corn ash can be used for low-strength concrete applications up to 3500psi in strength. The problem of low early age strength of concrete containing wood or corn ash can be solved using admixtures.

3. The literature was reviewed to determine the maximum replacement percentage of wood ash and corn ash in low-strength concrete. It was found that a maximum 15% wood ash replacement percentage could satisfy the compressive strength requirements of concrete (3000 psi). Similarly, it was found that a maximum 10% corn ash replacement percentage could satisfy the compressive strength requirements of concrete (3000 psi).

4. The average annual cement consumption in Florida was found out to be 4.8 million t. From this, the cement consumption for ready-mix concrete production was determined to be 3.36 million t. As the scope of study was limited to concrete less than 3500 psi, the cement required for low-strength concrete was determined to be 2.15 million t.

5. The 10% corn ash replacement obtained in conclusion 3 was used to determine the annual corn ash requirement for low-strength concrete in Florida. Therefore, replacing 10% of the annual cement consumption obtained in conclusion 4, a 215,000-t corn ash requirement was determined.

6. The annual corn harvest in Florida was found out to be 40,000 acres. With 145 bu./acre, Florida has 5.8 million bu. of corn. For 145 bu., 3.3 dry tons per acre of

dry stover is produced. Therefore, 5.8 million bu. of corn production could produce 132,000 t of corn waste. Assuming 5% ash generation, this waste had the potential of generating 6,600 t of corn ash annually in Florida. This could satisfy only 3% of the total corn ash required to replace fly ash.

7. The 15% wood ash replacement obtained in conclusion 3 was used to determine the annual wood ash requirement for low-strength concrete in Florida. Thus, the annual wood ash requirement was found out to be 322,500 tons. The annual wood waste generation in Florida was determined to be 3 million t. Assuming 4% ash generation, the potential wood ash generated annually in Florida was determined to be 120,000 t. This could satisfy 37% of the total wood ash required to replace fly ash.

8. The environmental impacts comprised of only the transportation energy emissions of wood ash and corn ash because both are byproducts of biomass plants. The emissions were measured as greenhouse gas emissions of CO_2 and CH_4. The transportation energy emissions of wood ash and corn ash were found to be 0.0034MTCE/t and 0.0024MTCE/t in Orlando respectively. These were higher than the transportation energy emission of fly ash in Orlando (0.0016MTCE/t). Similarly, the wood ash, corn ash and fly ash emissions in Miami were found to be 0.0012MTCE/t, 0.0024MTCE/t and 0.0032MTCE/t respectively.

9. Similar study and analysis showed that the cost per ton of wood ash and corn ash was $24-38/t and $45-75/t respectively. The cost per ton of fly ash was $35/t.

10. The wood ash generated from 3 million t in annual wood waste is 120,000 t. The average disposal fee charged by landfill sites in Florida is $30/t. Therefore, using this wood ash in concrete can reduce the annual landfilling cost by $3.6 million.

Based on the properties of wood ash and corn ash studied, they can be a suitable replacement to fly ash in low-strength concrete applications. The potential availability of wood ash being 37%, it can be used as a partial replacement to fly ash in concrete. However, the potential availability of corn ash is very low (3%). Therefore, it will be necessary to look at additional sources of corn ash, possibly from the Midwest region. However, the cost of transporting this corn ash to Florida would be high and is beyond the scope of the study. The transportation energy emissions of wood ash and corn ash are high because of the higher distance of transportation to Orlando. This is because of their low availability compared to fly ash. On the other hand, due to the proximity of sources near Miami, the transportation emissions of wood ash and corn ash are low compared to fly ash in Miami. The difference in cost per ton of wood ash and fly ash is only $4/t. Therefore, wood ash can be considered as a partial replacement to fly ash. The difference in cost per ton of corn ash and fly ash is $25/t which would result in a considerable increase in cost of concrete.

5.2 Research Limitations

The data used for comparing the physical and chemical properties of concrete containing wood ash and corn ash were not based in Florida. Many papers studied were from outside the United States. The properties of wood ash and corn ash are dependent on the type of wood waste and corn waste. The study did not include the sources of wood ash and corn ash outside Florida because the cost and energy required to transport the materials would be considerable. The cost data used for determining the cost per ton of wood ash was taken from Wisconsin, whereas that of corn ash was taken from Missouri.

5.3 Future Scope

The transportation energy emissions are based on the transportation distances of wood and corn ash from biomass plants. Therefore, using the Geographic Information System to identify the best locations for installing biomass plants not only for the generation of electricity but also for using the byproducts for cement replacement in concrete would help reduce energy emissions. More experimental work such as studying the compressive and tensile strengths of wood ash and corn ash in concrete will help to explain properties of wood ash and corn ash obtained from sources in Florida.

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