UNIVERSITY OF NORTH DAKOTA
UND.edu
COLLEGE OF ENGINEERING & MINES

Department of Civil Engineering
Upson II, Room 260
243 Centennial Dr Stop 8115
Grand Forks, ND 58202-8115
Phone: 701.777.3562
Fax: 701.777.3782
Website:civilengineering.UND.edu

March 31, 2021

Karlene Fine
Executive Director
ATTN: Lignite Research, Development and Marketing Program
North Dakota Industrial Commission State Capitol - 14th Floor
600 East Boulevard Ave Dept 405
Bismarck, ND 58505-0840

Dear Ms. Fine:

Please find enclosed here in the proposal titled, Determining Optimum Coal Bottom Ash Content for Sustainable Concrete Infrastructure. The main criteria for sustainable infrastructure are minimizing the use of natural resources and mitigating impacts on energy consumption, greenhouse gas emissions, environmental pollution, health, safety, and risk prevention while ensuring a high level of user comfort and safety. The potential effects of nanomaterials on concrete infrastructure in terms of sustainability lie in the efficient use of existing materials either through reworking or structural changes to ensure that the material's properties are improved, which will lengthen the concrete's life. The use of coal bottom ash (CBA) in concrete reduces cost, conserves energy and resources, reduces environmental impact, and enhances workability and durability. The main objective of this project is to test the hypothesis that there is an optimum content of CBA as a fine aggregate and cement replacement. Tests will be performed with and without nanoclay to create concrete that is either similar or higher quality in terms of mechanical properties and durability compared to pure Portland cement-based concrete, which will be used as a control.

The research team has the experience and expertise to complete the research within the schedule and budget. UND Civil Engineering is committed to complete the project as described in the application if the North Dakota Industrial Commission makes the grant requested.

We welcome an opportunity to discuss this proposal at greater length with you and look forward to working with you. Please let us know if you have questions. We will send a check for $100 for the application fee.

Sincerely,

DocuSigned by:
Daba Gedafa
F92218D8FEDA4FC...
Daba S. Gedafa, Ph.D., P.E., ENV SP
Principal Investigator
Office: 701-777-3976
Email: daba.gedafa@und.edu

DocuSigned by:
Karen Katrinak
DD9BE15BC81D4AA...
Karen Katrinak, Ph.D.
Proposal Development Officer
Office: 701-777-2505
Email: Karen.katrinak@und.edu

Determining Optimum Coal Bottom Ash Content for Sustainable Concrete Infrastructure

Applicant and Principal Investigator:

Daba S. Gedafa, Ph.D., P.E., ENV SP
Chair and Associate Professor
UND Civil Engineering
Upson II Room 260A
243 Centennial Dr. Stop 8115
Grand Forks, ND 58202-8115
Tel. (701) 777-3976
E-mail: daba.gedafa@und.edu

Co-Principal Investigator:

Bruce Dockter, M.S., P.E.
Sr. Lecturer/Lab Manager
UND Civil Engineering
Upson II Room 260N
243 Centennial Dr. Stop 8115
Grand Forks, ND 58202-8115
Tel. (701) 777-6078
E-mail: bruce.dockter@und.edu

Date of Application: April 1, 2021

Amount of the Request: $118,614

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ABSTRACT

The main criteria for sustainable infrastructure are minimizing the use of natural resources and mitigating impacts on energy consumption, greenhouse gas emissions, environmental pollution, health, safety, and risk prevention while ensuring a high level of user comfort and safety. The potential effects of nanomaterials on concrete infrastructure in terms of sustainability lie in the efficient use of existing materials either through reworking or structural changes to ensure that the material's properties are improved, which will lengthen the concrete's life. The use of coal bottom ash (CBA) in concrete reduces cost, conserves energy and resources, reduces environmental impact, and enhances workability and durability. The main objective of this project is to test the hypothesis that there is an optimum content of CBA as a fine aggregate and cement replacement. Tests will be performed with and without nanomaterials to create concrete that is either similar or higher quality in terms of mechanical properties and durability compared to pure Portland cement-based concrete, which will be used as a control. We anticipate that CBA and nanoclay use in concrete will improve workability and reduce water demand, the corrosion of the reinforced steel, segregation, bleeding, heat evolution, and permeability. The use of these materials will also inhibit alkali-aggregate reactions and enhance sulfate resistance, in addition to increasing economic and environmental benefits. The project will be for a duration of 15-months with a cost of $289,271. The cost per participant is: North Dakota Industrial Commission (41%), UND Civil Engineering (52%), and private companies (7%).

PROJECT SUMMARY

The main criteria for sustainable infrastructure are minimizing the use of natural resources and mitigating impacts on energy consumption, greenhouse gas emissions, environmental pollution, health, safety, and risk prevention while ensuring a high level of user comfort and safety. The potential effects of nanomaterials on concrete infrastructure in terms of sustainability lie in the efficient use of existing materials either through reworking or structural changes to ensure that the material's properties are improved, which will lengthen the concrete's life.

The use of coal bottom ash (CBA) in concrete reduces cost, conserves energy and resources, reduces environmental impact, enhances workability, and improves durability. The main objective of this project is to test the hypothesis that there is an optimum content of CBA as a fine aggregate and cement replacement. Tests will be performed with and without nanomaterials to create concrete that is either similar or higher quality in terms of mechanical properties and durability compared to pure Portland cement-based concrete, which will be used as a control. Optimum CBA and nanoclay content will be determined by comparing the compressive strength of this enhanced concrete to the control. Nanoclay and ground CBA from five power plants in North Dakota will be used to replace cement in concrete. Fresh properties, mechanical properties, and concrete durability will be determined based on the optimum content of CBA and nanoclay. The fresh properties that will be evaluated include slump, unit weight, and air content. Mechanical properties, including compressive strength, flexural strength, split tensile strength, and the modulus of elasticity will be determined using Universal Testing Machine following ASTM standards. The concrete's durability, including freeze-thaw resistance, rapid chloride penetration, and air content will be determined using ASTM or AASHTO standards. Statistical analysis (analysis of variance and t-tests) will be conducted at a 5% significance level to determine equivalency between the control and BCA-based concrete.

1. PROJECT DESCRIPTION

1.1 Objectives

The main criteria for sustainable infrastructure are minimizing the use of natural resources and mitigating impacts on energy consumption, greenhouse gas emissions, environmental pollution, health, safety, and risk prevention while ensuring a high level of user comfort and safety *(Maher et al. 2006)*. The potential effects of nanomaterials on concrete infrastructure in terms of sustainability lie in the efficient use of existing materials either through reworking or structural changes to ensure that the material's properties are improved, which will lengthen the concrete's life *(Cassar 2005)*.

The main objective of this project is to test the hypothesis that there is an optimum content of CBA as a fine aggregate and cement replacement. Tests will be performed with and without nanomaterials to create concrete that is either similar or higher quality in terms of mechanical properties and durability compared to pure Portland cement-based concrete, which will be used as a control. Nanomaterials can accelerate the rate of CBA's hydration reaction when used as a fine aggregate replacement, and ground coal bottom ash (GCBA) can improve its desirable properties when used as a Portland cement replacement, particularly at an early age. Specific objectives in this project include:

- To determine the optimum content of CBA as a fine aggregate replacement, and GCBA as a Portland cement replacement with and without nanomaterials by comparing to the control.
- To evaluate the effects of the optimum content of CBA as fine aggregate replacement, and GCBA as a cement replacement on fresh properties, mechanical properties, and durability of concrete compared to the control.

- To compare the air void distribution of fresh concrete and hardened concrete in terms of spacing factor.

1.2 Methodology

1.2.1 Selection of Materials

Due to the exponential growth of the population and the availability of limited natural resources, extensive scientific exploration has been completed to identify additional available raw materials that can be engineered and utilized. The most available raw minerals, such as clay, have significant potential for use in the construction industry. Nanoclay will be used in this project based upon their performance and availability, which is essential for large concrete infrastructure projects.

CBA will be supplied by Basin Electric Power Cooperative, Great River Energy, Montana-Dakota Utilities Company, Minnkota Power Cooperative, and Ottertail Power Company *(see letters of commitment)*. Boral Resources will provide GCBA including chemical and physical analysis for the same CBA (*see letter of commitment*).

1.2.2 Experimental Plan

The replacements for fine aggregates and cement will be CBA from coal-fired plants and GCBA. CBA content, GCBA content, nanoclay content, and curing periods will be analyzed for optimal use. At least three specimens will be tested in each test category to ensure sufficient data for statistical analysis. Table 1 lists the testing methods used to determine fresh properties, mechanical properties, and concrete durability.

The experimental plan will include the preparation and testing of five broad concrete test categories: (1) Ordinary Portland cement-based concrete as the control, (2) CBA-based concrete, (3) GCBA-based concrete, (4) CBA and nanoclay-based concrete, and (5) GCBA and nanoclay-based concrete. The optimum replacement amounts of CBA, GCBA, and nanoclay will be determined by comparing the compressive strength of the different combinations to the control. CBA and GCBA content will be increased at a 10% and 5% rate, respectively, to reach the optimum threshold. Nanoclay content, measured as percent by weight, will be tested starting with an initial value of 0.5%, and increased by 0.5% until the optimum content is achieved, or properties equivalent to or better than the control are reached. Studies have indicated that different optimum amounts of nanomaterials will produce ideal mechanical properties *(Chang et al. 2007, Givi et al. 2010, Mondal et al. 2010).*

Table 1. Properties, Curing Period, and Equipment

Property		Curing Period (days)	Equipment
Fresh Properties	Slump	0	Slump content
	Unit weight		Super Air Meter
	Air content		
Mechanical Properties	Compressive strength	7, 28, 56, 90	Universal Testing Machine
	Flexural strength		
	Tensile strength		
	Modulus of elasticity		
Durability	Freeze-thaw Resistance		Rapid Freeze-thaw Cabinet
	Chloride penetration		Rapid chloride penetration
	Air content		Linear Traverse

1.2.2.1 Mix Design and Mixing

Mix design information and ingredients will be obtained from three projects completed during the 2021 construction season *(see letters of commitment from Aggregate Industries, Border States Paving and Strata Corporation).* Adjustments in the mix designs will be created to account for the CBA, GCBA, fine aggregate, and cement specific gravity differences *(Kim 2015)*.

The effective dispersion of nanomaterial is critical in achieving the full benefits of a cementitious system. Self-aggregation, especially at high dosages of nanomaterials, is a common concern *(Qing et al. 2006, Sobolev et al. 2006, Veras-Agulho et al. 2009, Ozyildirim and Zegetosky 2010, Sanchez and Sobolev 2010*) as it sometimes leads to nonhomogeneous microstructure development and poor performance. The application of super-plasticizer and high-speed mixing was effective in the proper dispersion of nanomaterials *(Sobolev et al. 2006, Flores et al., 2010)*. We will mix nanoclay with a super-plasticizer at high-speed in this project.

1.2.2.2 Fresh Properties

Fresh property tests will include unit weight, air content, slump, and temperature. The loss of air content from fresh concrete increases with a higher nanomaterial content; however, the required concrete air content can be achieved by increasing the dosage of air-entraining admixture *(Gonzalez et al. 2013)*. The Super Air Meter (SAM) will be used to measure both the air void size and air volume of the fresh concrete following AASHTO TP 118. Small air bubbles will improve the freeze-thaw durability, reduce air loss over time, and increase the concrete's strength for a given volume of air. The unit weight of fresh concrete will be measured following ASTM C138M. Slump will be determined following ASTM C143.

The introduction of nanomaterials into concrete results in a workability loss due to the high specific surface area of the nanomaterials *(Bjornstrom et al. 2004, Hiisken and Brouwers 2008, Hosseini et al. 2009, Senff et al. 2010, Gonzalez et al. 2013)*; therefore, Super-plasticizers will be added to improve the workability.

1.2.2.3 Mechanical Properties

This research will identify whether or not the mechanical properties of BCA and GCBA with and without nanoclay-based concrete can be equivalent to or better than the control. The mechanical properties of concrete, including compressive strength, flexural strength, split tensile strength, and the modulus of elasticity, will be measured using a Universal Testing Machine (UTM).

Compressive Strength: Concrete can develop significant compressive strength, which is used to design structural elements in civil infrastructure. The addition of nanomaterials improves the compressive strength of concrete *(Flores et al. 2010, Gaitero et al. 2010, Gonzalez et al. 2013)*, which will be tested using a Universal Testing Machine after proper curing following ASTM C39.

Prior to the concrete testing the five GCBA materials will be evaluated for compressive strength using ASTM Standard Test Method C109. This standard test method is commonly used for assessing coal byproducts for potential strength development in cementitious applications. It is only designed to give an indication of the effect of an ash on concrete strength development but has the advantage of requiring smaller quantities of raw materials for its use. Thus a variety of mixtures can be incorporated if desired.

Flexural Strength: Flexural strength, also known as the modulus of rupture, bending strength, or fracture strength, is a critical mechanical property for brittle material and is defined as a material's ability to resist deformation under load. This property is used primarily to design concrete pavements. ASTM C78 will be followed to test concrete beam specimens for flexural strength using Universal Testing Machine.

Split Tensile Strength: The tensile strength of concrete is only a fraction of its compressive strength. Increased tensile strength allows for greater bending before rupture and can minimize the shrinkage cracking potential of concrete. Creating pavement with greater ductile properties allows designers to reduce the thickness of pavements and bridge decks, as well as significantly increasing the spacing of joints or eliminating them. Both structures and pavements will possess an increased ability to withstand dynamic loadings, prolonging the useful life of these constructions *(Metaxa et al. 2009)*. The incorporation of nanoclay can enhance the tensile strength of a cement composite *(Morsy et al. 2010)*, which can be tested using a split test method according to ASTM C496.

Modulus of Elasticity and Poisson's Ratio: Stress and strain will be measured using Universal Testing Machine according to ASTM C469 and will be used to calculate the concrete's modulus of elasticity. Poisson's ratio will be calculated as the ratio of measured transverse and axial strains.

1.2.2.4 Durability of Concrete

Durable transportation infrastructure needs to satisfy the requirements service with a minimum requirement for maintenance and sustainability. The durability requirement focuses on the potential perpetual use of the facility and the minimum requirements of disruptive maintenance and rehabilitation *(Li et al. 2006)*. All failure mechanisms associated with concrete durability involve the transportation of fluids through the concrete microstructure. The addition of nanomaterials increases the durability and service life of concrete by reducing fluid permeability and controlling calcium leaching *(Gaitero et al. 2010, Porro et al. 2010, Zhang and Li 2011, Zhang and Wang 2013)*. The durability of concrete is critical if it is exposed to deicing chemicals under freeze-thaw conditions in cold regions such as North Dakota. The freeze-thaw resistance, rapid chloride penetration, and air content of hardened concrete will be determined.

Freeze-Thaw Resistance**:** The movement of water into and through concrete can contribute to many deterioration mechanisms that affect performance. Water intrusion can result in freeze–thaw damage if a proper air-entraining system is not in place. In northern climates such as North Dakota, deicing chemicals can adversely affect concrete longevity if its properties are marginal or inadequate. Nanomaterials can significantly increase the life of concrete structures if a method is developed to create materials with a lower permeability, which will pave the way to enhancing freeze–thaw resistance without air entrainment *(Grove et al. 2010)*. The Rapid Freeze-Thaw Cabinet will be used to measure the concrete's deterioration resistance caused by repeated cycles of freezing and thawing following ASTM C666 Standard procedure.

Rapid Chloride Penetration test (RCPT)**:** Chloride permeability tests indicate the durability of concrete after severe exposure, as reported by *Argiz et al. (2018)* who determined that concrete made with GCBA additions improved performance in the presence of chloride. The addition of GCBA leads to lower migration and diffusion coefficients than concrete made without it. The fineness of cementitious material influences the pozzolanic activity and pore-filling action. ASTM C1202 will be followed to run an RCPT.

Air Content of Hardened Concrete: The air void spacing factor will be determined following ASTM Standard C457. This standard relies on the microscopic examination of polished concrete sections. The concrete cylinders will be cut in half longitudinally to create two specimens that will be polished and blackened, followed by barium sulfate void fills and the measurement of air void parameters.

1.2.2.5 Statistical Analysis

Paired t-tests will be performed to evaluate if there is a significant difference between the control and the properties of BCA and GCBA concrete with and without nanoclay *(SAS Institute, Inc. 2005)*. A paired t-test result can be expressed in terms of p-value, allowing us to determine if the null hypothesis should be rejected (*Ott and Longnecker 2001)*. A significance level of 5% will be used for all paired t-tests. An analysis of variance (ANOVA) will also be conducted at the same significance level using Statistical Analysis Software (SAS).

1.3 Anticipated Results

BCA has many of the same chemical properties of Portland cement, such as silica, alumina, iron, and other oxides, which allows it to be used as a replacement. We anticipate that the use of CBA, GCBA, and nanoclay in concrete will improve workability, reduce water demand, optimize heat evolution, enhance permeability, inhibit alkali-aggregate reactions, improve mechanical properties, and increase the concrete's durability in addition to maximizing economic and environmental benefits.

1.4 Facilities and Resources

1.4.1 Material Testing Laboratory and Equipment

The Department of Civil Engineering at the University of North Dakota hosts a 625 square meter research laboratory dedicated to civil engineering materials testing in Upson I, Rooms 112 and 113. The laboratory is fully equipped with state-of-the-art facilities that will be used to test civil engineering materials. All equipment needed for this project are located in this laboratory and include:

Aggregate Testing: All equipment needed for sieve analysis, specific gravity, bulk density, moisture content, and absorption of aggregates.

Mixing: Three high-speed mixers.

Fresh Property: Equipment to measure density and slump cones for determining the slump of fresh concrete. The Super Air Meter (SAM) will be purchased to measure both the air void size and air volume of fresh concrete *(See quote)*.

Curing: A large moist curing room (5 m x 5 m) with temperature and moisture control. There are three layers of shelves on the three sides of the room.

Mechanical Properties: Two Universal Testing Machines to determine compressive strength, flexural strength, split tensile strength, and the modulus of elasticity for the hardened concrete specimens.

Durability Test: Rapid Freeze-Thaw Cabinet to determine the concrete's deterioration resistance caused by repeated cycles of freezing and thawing in water and linear traverse to determine the air void content of hardened concrete. Equipment for rapid chloride penetration tests will be purchased *(see quote)*.

1.4.2 Human Resource and Facilities

Two ½-time (20 hours per week) graduate research assistants will work on this project under the guidance of the investigators, Dr. Gedafa and Mr. Dockter. An administrative assistant will assist with payroll, student hiring, and equipment and supply ordering.

The investigators have 4 m x 4 m office space with personal computers and high-speed internet access in Upson II Room 260, which is adjacent to the laboratory located in Upson I. Graduate research assistants have office space in Upson I that is close to the laboratory and includes personal computers with high-speed internet connections. All computers have the programs and software installed that are required for this project.

1.4.3 Library

The University of North Dakota (UND) has seven libraries. The Chester Fritz Library is the largest library at the university and within the state of North Dakota. The library houses over two million print and non-print items and is designated as the U.S. Patent and Trademark repository for Federal and State documents. It also houses a Special Collections Department preserving unique publications, manuscripts, historical records, and genealogical resources. The research team can access any relevant publications through Interlibrary Loan (ILL) services provided by the Library.

1.5 Environmental and Economic Impacts of the Project while it is Underway

The research team does not anticipate negative impacts on the environment and economy while the project is underway.

1.6 Ultimate Technological and Economic Impacts

This project has the potential to be transformative. It will have a significantly positive impact on the environment, water, energy, durability, and maintenance cost of concrete infrastructure, as well as the cost to infrastructure users. Additional information is located in the "Value to North Dakota" section.

1.7 Why the Project is needed

The domestic production of Portland cement in the United States was 82.7 million tons in 2014 *(U.S. Geological Survey 2015)*. The annual energy consumption associated with this production was approximately 554 trillion joules *(Choate 2003)*. Ordinary Portland cement, which is the main binder of ordinary Portland cement-based concrete, represents approximately 88% of all concrete CO_2 emissions *(Shi et al. 2011)*. The cement industry is responsible for approximately 8% of the global anthropogenic CO_2 emissions with an annual production rate of 2.35 billion tons *(BASF 2008)*. The use of concrete, therefore, results in 2.11 million metric tons of CO_2, based on the assumption that for each ton of ordinary Portland cement, 0.9 tons of CO_2 is released *(Gartner 2004)*. Ordinary Portland cement clinker production consumes large amounts of energy and involves massive quarrying for raw materials. Ordinary Portland cement demand is expected to increase to 200% by 2050 from 2010 levels, reaching 6,000 million tons per year globally *(Shi et al. 2011)*.

Approximately 32% of the BCA produced in the US is utilized (Table 2) *(ACAA 2020)*; therefore, unused BCA is disposed of in landfills located across thousands of acres of land. The disposal of BCA poses a risk to human health and the environment as the hazardous constituents migrate and can contaminate ground or surface water, soil, and living organisms. Environmental concerns are increasing, and land fill space is declining; therefore, it is essential to initiate efforts to utilize more CBA since there is a decline in natural sand as a fine aggregate source *(Singh and Siddique 2013, Bajare et al. 2013, Nikbin et al. 2016)*. The loss of these resources creates a critical need to investigate the use of BCA, GCBA, and nanoclay-based concrete for sustainable infrastructure.

Table 2. 2019 Bottom Ash Production and Use in America ***(ACAA 2020)***

Purpose	**Amount (Short Tons)**
Concrete/Concrete Products/Grout	332,036
Blended Cement/Feed for Clinker	910,914
Structural Fills/Embankments	532,276
Road Base/Subbase	105,869
Soil Modification/Stabilization	126,719
Mineral Filler in Asphalt	4,711
Snow and Ice Control	73,720
Blasting Grit/Roofing Granules	326,281
Waste Stabilization/Solidification	57,689
Agriculture	2,449
Aggregate	137
Oil/Gas Field Services	436
CCR Pond Closure Activities	357,558
Miscellaneous/Other	56,391
Total Used	2,923,586
Total Used in Percent	31.95

2. STANDARDS OF SUCCESS

If BCA, GCBA, and nanoclay-based concrete is equivalent to or better than the control in terms of mechanical properties and durability, the project will be successful provided that it will be completed within the schedule and budget.

3. BACKGROUND

3.1 Coal Bottom Ash

Coal ash is a non-combustible material produced by coal-fired power plants. The finer and lighter particles of coal ash escape with flue gases and are extracted in Electrostatic Precipitators before entering the environment. Melted ash accumulates on boiler walls and in steam tubes, solidifying to form masses called clinkers. These clinkers build up and fall to the boiler or furnace's bottom and are cooled in the water sump pump before passing through the clinker grinder. The coal ash collected at the bottom of the furnace is bottom ash, which accounts for up to 25% of the total amount, with fly ash accounting for the remaining 75% (Figure 1) *(Abubakar and Baharudin 2012, Singh and Siddique 2013).*

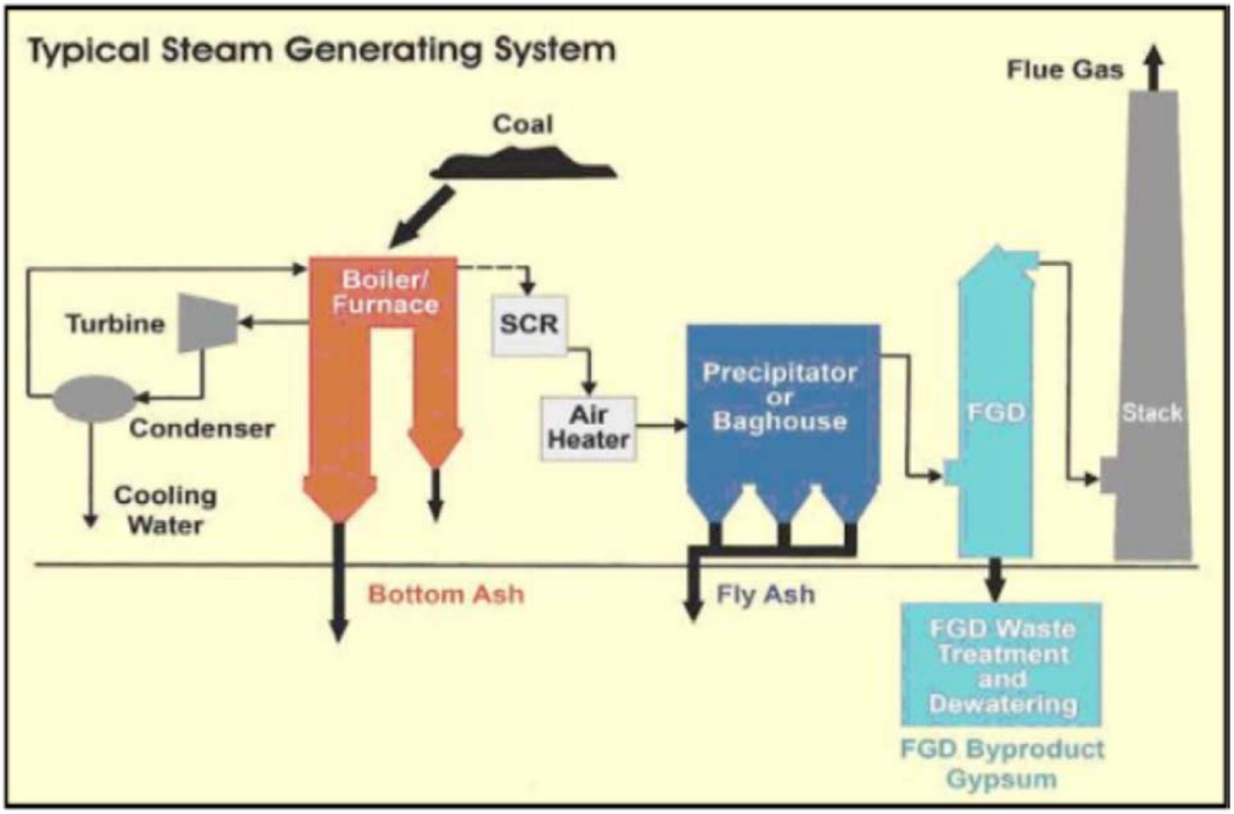

Figure 1. Typical CBA production ***((Abubakar and Baharudin 2012).***

3.1.1 Chemical Properties and Pozzolanic Reactivity of CBA

CBA is composed primarily of silica, alumina, and iron with small amounts of calcium, magnesium, sulfate, and other constituents. A higher silica content makes CBA hydrophilic, which eventually attracts water to its surface *(Malkit and Rafat 2013)*. The chemical composition of CBA depends on the source of coal and furnace conditions *(Singh and Siddique 2013, Muhardi et al. 2010, Namkane et al. 2016).* The desired pozzolanic activity can be obtained after grinding the CBA due to the presence of silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3) *(Filipponi et al.*

2003, Martins and Gonçalves 2010). These compounds react with calcium hydroxide ($Ca(OH)_2$) during the hydration process to form additional calcium silica hydrates (C-S-H) and Calcium aluminate hydrates (C-A-H) *(Singh 2018).*

3.1.2 Physical Properties of CBA

The physical properties of CBA depend on the variability of the parent rock fragments collected from different sources, and the degree of pulverization and firing temperature. CBA particles are angular, irregular, and porous with a rough surface texture. Particle sizes range from fine gravel to fine sand with interlocking characteristics. The sizing gradation indicates that 80%-90% particles pass through a 4.75 mm sieve, 10%-60% particles pass through a 600-micrometer sieve, and 0%-15% particles pass through a 75-micrometer sieve *(Singh 2018).* The water absorption of CBA ranges from 5% to 32% *(Ghafoori and Bucholc 1996)*, the specific gravity varies from 1.39 to 2.33 depending upon its chemical composition *(Singh and Siddique 2013)*, and the fineness modulus varies from 1.39 to 2.88 depending on the quality and source of the coal *(Singh and Siddique 2013).*

3.2. Uses of Bottom Ash in Concrete

Many researchers have used CBA to partially replace the fine aggregate, or sand, due to the appropriate size, physical characteristics, and mechanical properties and durability *(Singh and Siddique 2016, Lynn et al. 2016, Rafieizonooz et al. 2016, Hashemi et al. 2018, Kim et al. 2014, Aggarwal and Siddique. 2014).* GCBA may be used as a pozzolanic material to replace Portland cement in concrete *(Chindaprasirt et al. 2009, Argiz et al. 2018)*, with an optimum replacement rate of 10% to improve the mechanical properties and durability of the concrete *(Argiz et al. 2018, Mangi et al. 2019).*

3.2.1. Effect of CBA as a Fine Aggregate Replacement on Mechanical Properties

Compressive strength: Some researchers have examined a concrete's compressive strength after entirely replacing the fine aggregate with CBA, resulting in an approximate 70% compressive strength reduction compared to the control *(Rafieizonooz et al.2016, Singh and Siddique, 2016).* Replacing fine aggregate with CBA has also resulted in a reduced compressive strength after a shorter curing time of up to 28 days (*Abhishek and Khurana 2015, Soman et al. 2014, Ranapratap and Padmanabham 2016)*. A fine aggregate replacement of up to 10% CBA resulted in an increase in compressive strength, whereas a further increase in the amount of added CBA results in the reduction of compressive strength. Marginal reductions have been noticed for 20% and 30% fine aggregate CBA replacement *(Abhishek and Khurana, 2015, Soman et al. 2014, Rafieizonooz et al. 2016),* whereas a significant reduction has been recorded when replacing fine aggregates with 50% CBA compared to the control *(Sanjith et al. 2015, Prasanna and Annaduria 2015)*. Some of these variations may be due to the increased pozzolanic activity of CBA to overcome the other negative effects such as porosity and permeability, which may be responsible for the reduction in compressive strength.

Flexural Strength: Many studies evaluated fine aggregate CBA replacement for lower (up to 30%) and higher levels (> 30%) of percentage by weight at different curing periods *(Soman et al. 2014, Abhishek and Khurana 2015, Prasanna and Annaduria 2015)*. Replacing up to 10% of the fine aggregate with CBA resulted in an increase in flexural strength at 28 days of curing *(Prasanna and Annaduria 2015).* A significant reduction in flexural strength compared to the control has been observed with higher replacement levels (≥30%) *(Park et al. 2009)*; however, flexural strength decreased up to 30% with higher replacement levels (30%–50%) *(Prasanna and Annaduria 2015, Abhishek and Khurana 2015).*

Split Tensile Strength**:** Past studies have indicated that using CBA as a replacement for natural fine aggregates results in an increase in tensile strength at different curing periods *(Soman et al. 2014, Sanjith et al. 2015, Prasanna and Annaduria 2015)*. CBA use leads to additional pozzolanic reactions, which further improves the quality of cement paste and interfacial transition zones. This improvement is the primary reason for the enhancement in split tensile strength (*Remya et al. 2014)*, ranging from an observed 5% to 15% gain compared to the control after 28 days of curing and with a replacement level of up to 20% *(Sanjith et al. 2015, Prasanna and Annaduria 2015)*. The tensile strength was reduced significantly, up to 29%, for curing periods of 28 days for CBA levels ranging from 30% to 50% *(Soman et al. 2014, Prasanna and Annaduria 2015).* The study conducted by *Malkit and Rafat (2016)* concluded that the replacement of CBA with fine aggregates for different fineness modulus decreased the tensile strength marginally with up to 28 days of curing. The tensile strength of CBA-based concrete was comparable to the control for longer curing periods.

Modulus of Elasticity**:** An increase in the level of CBA sand replacement causes the modulus of elasticity to decrease. CBA particles are less stiff and dense than natural sand particles; therefore, its use in concrete results in weak and porous paste, which further results in a reduction of the concrete's modulus of elasticity. The application of chemical admixtures results in an improvement in the concrete's modulus of elasticity because of the lower water to cement ratio. *Kim and Lee (2011)* determined that the modulus of elasticity decreased with an increase in the replacement of fine and coarse CBA as aggregates. *Topcu and Bilir (2010)* observed that bottom ash concrete's modulus of elasticity decreased from 60 GPa to 17 GPa with an increase in CBA of 0% to 60–100%. *Andrade et al. (2009)* demonstrated that the concrete's modulus of elasticity at a

28-day curing age decreased from 25.8 GPa to 8.9 GPa when the bottom ash replacement ratio increased to 100%.

3.2.2. Effect of CBA as a Fine Aggregate Replacement on Durability

Freeze–thaw Resistance: *Ghafoori and Cai (1998)* observed that the non-air entrained CBA-based concrete performs well in an environment with repeated freezing and thawing cycles. Tested specimens completed 300 rapid freezing and thawing cycles with a maximum mass loss of 2.3% and a minimum durability factor of 91.2%. Both cumulative mass loss and durability factors exhibited linear relationships with freezing and thawing cycles. *Ghafoori and Bucholc (1996)* concluded that despite a higher water to cement ratio, CBA concrete with a cement content of 356 kg/m^3 or more exhibited considerable performance increases when exposed to an environment with repeated freezing and thawing cycles.

Chloride Ion Permeability**:** The chloride ion permeability of concrete made with CBA has been evaluated by assessing the total chloride diffusion coefficient after 28 days of curing. Concrete containing CBA with a constant water to binder ratio performed as well as the control mix. The chloride ion penetration decreased gradually when the[5] replacement level of fine aggregates with CBA changed from 0% to 30% compared to the control after 28 days of curing *(Tuhran 2012).*

3.2.3. Effect of GCBA as a Cement Replacement

CBA must be ground to an appropriate ultra-fine level before it can be used as a cement replacement, as reported by *Oruji et al. (2017)*. Optimizing the GCBA content in concrete can increase reactivity, which will reduce the amount needed for each mix.

3.2.3.1. Effect of GCBA as a Cement Replacement on Fresh Properties

The behavior of freshly made concrete is vital to aid in understanding the overall performance of concrete. The presence of GCBA as an alternate material for Portland cement affects the fresh properties of concrete. The linking feature of GCBA particles enhances the inter-particle friction, thereby hampering the free flow of fresh concrete *(Cadersa and Auckburally 2014)*. As GCBA content increases, the workability of fresh concrete decreases *(Aminudin et al. 2015)* as the workability depends on the grinding period, the fineness modulus or gradation, and the source of collection, among other variables *(Mangi et al. 2019).*

3.2.3.2. Effect of GCBA as a Cement Replacement on Mechanical Properties

A shorter curing period of fewer than 28 days lowers the compressive strength of concrete with GCBA compared to the control. The compressive strength of the concrete with an approximate 10% GCBA replacement is similar to or higher than the control with curing periods of more than 28 days *(Jaturapitakkul and Cheerarot 2003, Canpolat et al. 2004, Kurama and Kaya 2008, Arenas et al. 2013, Brás and Faustino 2016).* An increase in the curing period results in an increase in the pozzolanic activity of GCBA due to the higher formation of hydration products at later ages, which results in increased compressive strength. A finer GCBA grind results in a higher comprehensive strength due to inherent pore refinement action as finer particles fill the pores in the paste, increasing the hydration products formed during pozzolanic reactions *(Targan et al. 2003, Oruji et al. 2017, Abdulmatin et al. 2018).*

3.3 Nanomaterials in Ordinary Portland Cement-based Concrete

Nanomaterial is the understanding and control of matter, at dimensions between approximately 1 and 100 nanometers *(Shatkin et al. 2014)*, where unique phenomena enable novel applications *(National Research Council 2006, Gammampila et al. 2010)*. The basic concept of using nanomaterial in construction applications is the employment of a large surface area to improve the compressive and flexural strength during an early age, enhance hydration, and reduce the porosity and water absorption compared to conventional cementitious materials *(Wahab et al. 2013, Rathi and Modhera 2014)*. The application of nanomaterials in construction will reduce the volume of cement needed, which can lower the usage of material and labor costs while reducing greenhouse emissions *(Bi et al. 2012)*.

3.3.1 CBA and Nanomaterial for Sustainable Concrete Infrastructure

CBA can be used as supplementary cementitious materials (SCMs) in concrete to reduce cost, conserve energy and resources, reduce environmental impact, and enhance workability. The use of SCMs can also improve concrete properties and increase the service life of concrete structures. One disadvantage of using high volumes of CBA is a delay in initial setting time due to drastically slow hydration, which reduces the early strength of concrete. The use of nanomaterials to accelerate the hydration rate of ordinary Portland cement or SCM blend creates the possibility of significantly lowering the content of cement in concrete *(Corr and Shah 2005, Sato and Beaudoin 2006, Sato and Beaudoin 2007)*, potentially reducing greenhouse gas production in the construction industry. The addition of nanomaterials can maximize the use of CBA without sacrificing the strength of concrete. The microstructure of cement mortar containing nanomaterials is denser than plain mortar and increases the rate of compressive strength after 3 to

28 days of curing time *(Shekari and Razzaghi 2011)*. GCBA increases the fineness and enhances the performance of CBA *(Bajare et al. 2013)*. The use of nanoclay is a promising enhancement for mechanical performance and resistance to chloride penetration while also reducing permeability *(Birgisson 2006, Kuo et al. 2006, He and Shi 2008, Morsy et al. 2009)*.

3.4 Hydration Reaction

Cement hydration is a complex set of interrelated chemical reactions leading to the stiffening of the fresh concrete, followed by strength gain and decreased permeability. Rates are affected by the system's materials and the environment to which it is exposed *(Taylor et al. 2007)*. The concrete hydration process continues for weeks or years if water is continually present. Cement hydration is an exothermic reaction that takes place in five different stages *(Young 1985)*, illustrated by a curve that represents the changes in heat during the first hours and days of hydration (Figure 2) *(Taylor et al. 2007)*.

Various nanomaterials can improve and densify the cement matrix, leading to improved permeability and strength. The nanomaterials act as "nuclei" of hydration, possessing pozzolanic behavior resulting in the consumption of $Ca(OH)_2$ and the formation of an "additional" Calcium-Silicate-Hydrate (C-S-H) *(Kang et al. 2001, Collepardi 2002, Kosmatka et al. 2002, Collepardi 2004)* that can fill the voids in the cement matrix *(Shih et al. 2006)*.

The hydration rate of CBA is low; therefore, it must be activated. Nanomaterials improve cementitious properties through two mechanisms: faster pozzolanic reactions due to higher nanomaterial surface area and improving the microstructure by acting as nucleation centers. The greater reactivity and the pozzolanic nature of nanomaterials further increase the reaction rate by reducing the number of calcium ions present in the hydration water *(Guerrero et al. 2005,* *Campillo et al. 2007, Chang et al. 2007, Jo et al. 2007, Lindgreen et al. 2008, Veras-Agulho et al. 2009, Gaitero et al. 2010, Mondal et al. 2010, Quercia et al. 2012).*

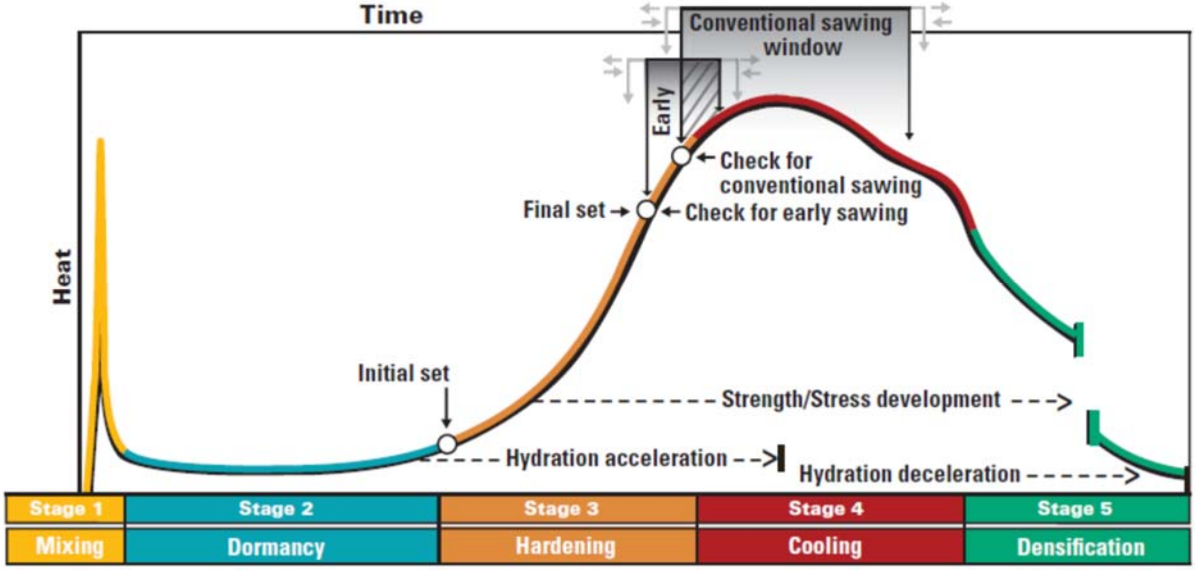

Figure 2. Five stages of hydration *(Taylor et al. 2007).*

4. QUALIFICATIONS

4.1 Principal Investigator (PI): Daba Gedafa, Ph.D., P.E., M.ASCE, ENV SP

The PI has extensive research, teaching, and industry experience in concrete materials and infrastructure as a registered Envision Sustainability Provisional and Professional Engineer in North Dakota and Connecticut. Dr. Gedafa investigated the use of fly ash and nanomaterials for sustainable concrete infrastructure for the NDIC, resulting in a peer-reviewed journal article publication. The PI researched the use of fly ash as an asphalt replacement and mineral filler for the NDIC to examine sustainable asphalt pavements, resulting in a peer-reviewed journal article currently under review for publication. He developed performance-related models for concrete pavements in Kansas and modeled concrete curling using the finite element method (FEM). Dr. Gedafa has investigated the effect of the concrete construction environment on the long-term performance of jointed plain concrete pavement and has evaluated 15-year performances of special pavement sections (SPS-2), which are the original concrete pavement sections on Interstate 70 in Kansas.

The PI has taught civil engineering materials courses that include material testing in the laboratory and report writing at four different institutions. The fresh properties of concrete that have been included in lecture and laboratory are density, air content, slump, and temperature. The mechanical properties of hardened concrete that have been covered are compressive strength, flexural strength, tensile strength, and the modulus of elasticity. He has been teaching civil engineering materials for ten years at the University of North Dakota, two years at the University of Connecticut, one year at Kansas State University, and one year at Arbaminch University in Ethiopia. The PI was the project engineer and acting project manager for the construction of the Durame District Hospital in Ethiopia. These experiences enable him to investigate the use of CBA, GCBA, and nanomaterial-based concrete for sustainable concrete infrastructure.

4.1.1 Pertinent Publications

1. Melaku, R.S. and **Gedafa, D.S.** (2020). "Impact of Wastewater Treatment Sludge on Cracking Resistance of HMA Mixes at Lower Mixing Temperature," *ASCE Journal of Materials in Civil Engineering*. **https://doi.org/10.1061/(ASCE)MT.1943-5533.0003506**

2. Saha, R., Melaku, R.S., Karki, B., Berg, A., and **Gedafa, D.S. (2020)**. "Effect of Bio-Oils on Binder and Mix Properties with High RAP Binder Content," *ASCE Journal of Materials in Civil Engineering*.https://ascelibrary.org/doi/10.1061/%28ASCE%29MT.1943-5533.0003057

3. Tolliver, S. and **Gedafa, D.S**. (2016). "Investigating the Use of Fly Ash and Nanomaterials for Sustainable Concrete Infrastructure," *International Journal of Engineering Research & Technology*, Vol. 5, No. 7, pp. 173-177.

4. **Gedafa D.S.,** Landrus, D., and Suleiman, N. (2016). “Effect of Nanoclay on Rutting Resistance of HMA Mixes,” *International Journal of Engineering Research & Technology*, Vol. 5, No. 5, pp. 47-52.
5. Haghshenas, H., Khodaii, A., Hossain, M., and **Gedafa, D.S.** (2015). “Stripping Potential of HMA and SMA: A Study Using Statistical Approach,” *ASCE Journal of Materials in Civil Engineering*, Vol. 27, No. 11.
6. **Gedafa, D.S.**, Hossain, M., Ingram, L. S., and Kreider, R. (2012). “Performance-related specifications for PCC pavements in Kansas,” *ASCE Journal of Materials in Civil Engineering*, Vol. 24, No. 4, pp. 479-487.
7. **Gedafa, D.S**., Hossain, M., Siddique, Z.Q., Fredrichs, K., and Meggers, D. (2012). “Curling of New Concrete Pavement and Long-Term Performance,” *Journal of Civil Engineering and Architecture,* Vol. 6, No. 2, pp. 121-131.
8. **Gedafa, D.S.**, Khanum, T., Hossain, M., and Schieber, G. (2011). “Effect of Construction Environment on JPCP Performance,” *Proceedings of 1st Transportation and Development Institute of the American Society of Civil Engineers Congress*, Chicago, IL, Vol. 2, pp. 834-843.
9. **Gedafa, D.S.,** Mulandi, J., Hossain, M., and Schieber, G. (2011). “Comparison of Pavement Design Using AASHTO 1993 and NCHRP Mechanistic–Empirical Pavement Design Guide,” *Proceedings of 1st Transportation and Development Institute of the American Society of Civil Engineers Congress*, Chicago, IL, Vol. 1, pp. 538-547.
10. Khanum, T., Hossain, M., Gisi, A., and **Gedafa, D.S. (2008).** “15-Year Performance of SPS-2 in Kansas,” *Proceedings of 9th International Conference on Concrete Pavements*, International Society of Concrete Pavements, San Francisco, CA, 976-994.

11. **Gedafa, D.S.,** Uppu, K.K., Hossain, M., Ingram, L.S., and Kreider, R. (2013). "Verification of Performance-Related Specifications for Superpave Pavements," *Transportation Research Board 91st Annual Meeting Compendium of Papers DVD/AMOnline,* Transportation Research Board of the National Academies, Washington, D.C.
12. **Gedafa, D.S.**, Hossain, M., Ingram, L. S., and Kreider, R. (2011). "Performance Related Specification for Superpave Pavements in Kansas," *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 2228, pp. 78-86.
13. **Gedafa, D.S.**, Hossain, M., Ingram, L. S., and Kreider, R. (2010). "Composite Pay Index for Superpave Pavements in Kansas," *Proceedings of 11th International Conference on Asphalt Pavement*, Nagoya, Japan, Vol. 1, pp. 709-718.
14. **Gedafa, D.S**., Hossain, M., Romanoschi, S. A., and Gisi, A. J. (2010). "Comparison of Moduli of Kansas Superpave Asphalt Mixes," *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 2154, pp. 114-123.
15. **Gedafa, D.S**., Hossain, M., Romanoschi, S. A., and Gisi, A. J. (2010). "Field Verification Of Superpave Dynamic Modulus," *ASCE Journal of Materials in Civil Engineering,* Vol. 22, No. 5, pp. 485-494.

4.2 Co-Principal Investigator (Co-PI): Bruce Dockter, M.S., P.E.

The CO-PI has extensive experiences in the field of coal byproduct utilization and coal combustion sciences. He has served as a research engineer and laboratory manager for 30 years with the Energy & Environmental Research Center (EERC) at UND. His research with coal byproducts utilization emphasized in applications with partial cement replacement in concrete, soil stabilization and amendment, controlled low strength materials, mineral admixtures in asphalt pavements, fly ash in ceramics, and the production of mineral wool. His activities in the area of high temperature research included evaluating viscosity characteristics of coal slags and resistance of material to simulated corrosive coal combustive environments. Research included both laboratory and field testing.

The CO-PI taught in the civil engineering department at UND since 2014. His responsibilities include teaching undergraduate courses, research activities, service activities and laboratory management. Course teachings include an introductory course to civil engineering, AutoCAD and Civil 3D, general surveying lecture and laboratory. Additional laboratory classes taught are materials testing, soil properties testing, demonstration of hydraulic principles and environmental laboratory testing.

4.2.1 Pertinent Publications

1. Dockter, B.A. (2011). *Using Class C Fly Ash to Mitigate Alkali-Silica Reactions in Concrete, Year 3*; Final Report (Nov 1, 2009 – Dec 31, 2011) for ASR Consortium Members, EERC Publication 2011-EERC-12-08, Energy & Environmental Research Center: Grand Forks, ND.
2. Dockter, B.A. and Jagiella, D.M. (2005). *Engineering and Environmental Specifications of State Agencies for Utilization and Disposal of Coal Combustion Products. Volume 1 – DOE Specifications*; Final Report (Sept 1, 2004 – Aug 31, 2005) for CBRC Project No. 02-CBRC-W12; EERC Publication 2005-EERC-07-04; Grand Forks ND.
3. Dockter, B.A. (1998). Comparison of Dry Scrubber and Class C Fly Ash in Controlled Low-Strength Materials (CLSM) Applications. In *The Design and Applications of Controlled*

Low-Strength Materials (Flowable Fill), ASTM STP 1331; Howard, A.K.; Hitch, J.L., Eds; American Society for Testing and Materials: pp 13-26.

5. VALUE TO NORTH DAKOTA

The objectives of transportation engineering can be defined as the supply of safe, durable, economical, and sustainable infrastructure for the movement of goods and people. America's infrastructure received a grade of C^- in 2021, and there is a $2.6 trillion funding gap over the next ten years, according to the ASCE report from 2021. Nanotechnology and nanoscale modifications can improve the strength of existing or new materials and provide a more cost-effective means of construction *(Halicioglu 2009)*.

One of the most important fields of application for the byproducts of coal-fired power plants is concrete production, where large quantities of concrete are used, and economy is a vital factor in construction. The use of CBA as a replacement for fine aggregate, and GCBA as a replacement for ordinary Portland cement in concrete can have environmental as well as economic benefits through the reduction of greenhouse gases, diversion of CBA from landfills, and the reduced use of natural resources for cement manufacturing *(Jachimovicz and Bentur 2008, Garboczi 2009)*. Durable transportation infrastructure results in billions of dollars in savings for maintenance costs (federal, state, local, and city highway agencies), reduced vehicle operating cost and travel time (traveling public), and improved safety for the society (highway agencies and traveling public).

5.1 Landfill

Environmental degradation and energy costs associated with mining virgin materials can be avoided by using CBA instead of disposing of it in landfills. The use of existing materials is also more environmentally and economically sound than mining new materials. America can reduce the need for additional landfills by recycling CBA: for each ton recycled, a space equivalent to 455 days' worth of solid waste is conserved *(EPA 2008)*.

5.2 Energy and Environment

Stronger and longer-lasting structures that save taxpayer dollars and minimize environmental impacts can be built using CBA. A ton of carbon dioxide is prevented from entering the Earth's atmosphere for every ton of GCBA used in place of Portland cement. A single ton of cement requires the use of 55 gallons of oil. The energy saved by using GCBA is equal to 24 days of electricity consumption for an average home. The use of these replacement materials conserves the energy necessary to extract and process other needed materials *(EPA 2008)*. The possibility of replacing Portland cement with GCBA offers technical and environmental benefits, which are of utmost importance for sustainable development *(Singh and Siddique 2015)*.

5.3 Water

Concrete created with CBA requires less water, produces a longer-lasting product, conserves limited resources, and reduces costs related to water consumption and equipment replacement. These benefits are essential for the State of North Dakota and its people, especially in the western part of the state where there is a high demand for water, which is necessary for oil well maintenance.

5.4 Economic Impact

The use of GCBA as a cement replacement yields many environmental benefits, including lower energy use, water consumption, and carbon dioxide emissions. Energy and water savings represent two significant impacts that can be monetized using market prices. Cement consumption is expected to increase at a faster rate due to the expected economic growth; therefore, using GCBA instead of Portland cement can reduce the cost of concrete in a project while improving its overall performance and durability.

6. MANAGEMENT

Two graduate research assistants (one Ph.D. and one M.S.) will work on this project under the supervision of Dr. Gedafa and Mr. Dockter. The research team will submit quarterly progress reports and ensure project completion within the schedule and budget.

7. TIMETABLE

The duration of the project will be 15 months from the start to end dates. The research team shall submit quarterly reports to the commission summarizing the project's accomplishments, expenditures, and adherence to the timing specified in the contract. The research team will submit a comprehensive final report to the commission within the time specified in the contract. This report will include a single-page project summary describing the project's purpose, the work accomplished, the project's results, and the potential applications of the project. The report's remainder will explain these subjects in detail as well as the total costs of the project, a summary fiscal accounting of the entire project, any plans for developing or using the results of the project commercially, and whether and in what manner the project met or failed to meet the standards referred to in subsection 7 of section 43-03-04-01.

8. BUDGET

Table 3 lists an itemized project cost that includes the money requested from the North Dakota Industrial Commission (NDIC) and matching funds. Two principal investigators (Dr. Gedafa and Mr. Dockter) and two ½-time graduate research assistants (one Ph.D. and one M.S.) will work on this project. The research team would like to request approximately 44% of the total project cost from NDIC to achieve the project's objectives. If less funding is available than requested, all the objectives may not be met, and the results may be inconclusive.

8.1 Budget Justification

8.1.2 Salary

Fifteen months of salary for two ½-time (20 hrs/week) graduate students (one Ph.D. and one M.S.), one month of summer salary for Dr. Gedafa, and two weeks of summer salary for Mr. Dockter has been requested from the North Dakota Industrial Commission (NDIC) for their efforts in this project.

8.1.3 Fringe Benefits

Fringe benefits have been calculated as 10% and 35% of the salary for graduate students and the investigators, respectively.

8.1.4 Materials and Supplies

Budget has been requested to purchase supplies to test fresh properties, mechanical properties, and durability of concrete.

8.1.5 Travel

The research team will travel to construction sites to collect raw materials, including travel to power plants to amass CBA. These funds may also be used to travel to national or international conference(s) to present research results.

8.1.6 Indirect Cost

Indirect cost has been calculated as 41% of the modified total direct cost (MTDC), which excludes equipment cost and graduate student tuition.

9. MATCHING FUNDS

UND Civil Engineering will provide matching funds at approximately 52% of the total project cost. Matching funds from private companies accounts for approximately 7% of the total project cost.

9.1 Budget Justification

9.1.1 Salary

Two months of salary for the two principal investigators' time on the project will be used as matching funds.

9.1.2 Fringe Benefits

The fringe benefits of the PIs, 35% of two months' worth of salary for each, will be used as matching funds.

9.1.3 Graduate Student Tuition

The UND civil engineering department will cover graduate student tuition for the project period of 15 months, which includes 30 credit hours for each international graduate student.

9.1.4 Equipment

UND civil engineering will purchase a Super Air Meter (SAM) to measure the air void size and the air volume of fresh concrete at a cost of $3,850. Equipment will also be purchased to determine rapid chloride penetration at a cost of $16,110. The quotes for the equipment are included.

9.1.5 Cash and In-kind Match

Great River Energy will provide $1,000 in cash in addition to providing CBA. Boral Resources will provide GCBA including chemical and physical analysis, which results in at least $10,000 in in-kind contribution according to Dr. Minkara from Boral Resources.

Table 3. Budget for the Project

	NDIC	Matching Fund		Total
		UND Civil Engineering	External Agencies	
Salary				
Dr. Gedafa (PI)	10722	21444		32166
Dr. Suleiman (Co-PI)	3849	15396		19245
Grad. Res. Ass't (Ph.D. stu.)	30,900			30900
Grad. Res. Ass't (M.S. stu.)	25,875			25875
Total Salary	**71346**	**36840**	**0**	**108186**
Fringe Benefits				
Dr. Gedafa (PI)	3752.7	7505.4		11258.1
Dr. Suleiman (Co-PI)	1347.15	5388.6		6735.75
Grad. Res. Ass't (Ph.D. stu.)	3090			3090
Grad. Res. Ass't (M.S. stu.)	2587.5			2587.5
Total Fringe Benefits	**10777.35**	**12894**	**0**	**23671.35**
Grad. Student Tuition				
Ph.D. Student		30,240		30240
M.S. Student		30,240		30240
Equipment		19960		19960
Cash and In-kind Match	0	0	11,000	11,000
Materials and Supplies	1,000		3,250	4250
Travel	1,000			1000
Total Direct Cost (TDC)	**84,123**	**130,174**	**14,250**	**228547.35**
Modified Total Direct Costs (MTDC)	**84,123**	**49,734**	**14,250**	**148107.35**
Indirect Cost (41% of MTDC)	**34,491**	**20,391**	**5,843**	**60724**
Total Project Cost	**118,614**	**150,565**	**20,093**	**289,271**

9.1.5 Materials and Supplies

CBA will be supplied by Basin Electric Power Cooperative, Great River Energy, Montana-Dakota Utilities Company, Minnkota Power Cooperative, and Ottertail Power Company. Aggregate Industries, Border States Paving, and Strata Corporations will provide concrete mix design information and raw materials from the 2021 construction season to create concrete in the laboratory. The total contribution in terms of materials and services from private companies accounts for $3,250. Total contribution from private companies in terms of cash, in-kind, materials and services is $14,250, which accounts for about 7% of the project cost.

9.1.6 Indirect Cost

Indirect cost has been calculated as 41% of the modified total direct cost (MTDC), which excludes equipment cost and graduate research assistants' tuitions.

10. TAX LIABILITY

No outstanding tax liability is owed to the state of North Dakota or any of its political subdivisions.

11. CONFIDENTIAL INFORMATION

There is no confidential information in this proposal.

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GREAT RIVER ENERGY®

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March 18, 2021

Daba S. Gedafa, Ph.D., P.E., ENV SP
Chair and Associate Professor of Civil Engineering
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Dear Dr. Gedafa,

Great River Energy is supportive of your research to determine the optimum coal bottom ash content for sustainable concrete infrastructure. The use of coal bottom as cement and fine aggregate replacement in concrete may result in structures that are stronger and more durable. It can also have environmental as well as economic benefits through diversion of coal bottom ash from landfills and reduced use of limited natural resources. Great River Energy is committed to provide $1,000 in addition to up to 500 pounds of coal bottom ash needed for the research and highly recommends this proposal for funding by Lignite Research Council.

Sincerely,

Al Christianson
Director, Business Development and Governmental Affairs

**BASIN ELECTRIC
POWER COOPERATIVE**
A Touchstone Energy® Cooperative

March 24, 2021

Daba S. Gedafa, Ph.D., P.E., ENV SP
Chair and Associate Professor of Civil Engineering
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Dear Dr. Gedafa,

Basin Electric Power Cooperative (Basin Electric) is pleased to provide support for UND's research regarding beneficial use of bottom ash in concrete applications. Basin Electric is a not-for-profit generation and transmission cooperative incorporated in 1961 to provide supplemental power to rural electric cooperatives. Basin Electric is consumer owned by 140 member cooperatives serving 3 million electric customers, and currently has over 7,000 MW of generation capacity within its resource portfolio including two lignite generation plants in the state of North Dakota.

As part of this project, Basin Electric pledges to provide, at Basin Electric's discretion, bottom ash samples from its lignite coal power plants as necessary for research purposes. Basin Electric looks forward to collaborating with UND on this research that has the potential to expand the beneficial use of lignite coal byproducts.

Sincerely,

David D Raatz
David D Raatz (Mar 24, 2021 11:37 CDT)

David D. Raatz
Sr VP of Asset Management,
Resource Planning and Rates

/aj

By email: daba.gedafa@und.edu

Cc: Daniel Schaaf Gallagher
Andrew Jones

MDU RESOURCES
GROUP, INC.

1200 W. Century Ave.
Bismarck, ND 58503
Mailing address:
P.O. Box 5650
Bismarck, ND 58506-5650
(701) 530-1000
www.MDU.com

March 29, 2021

Daba S. Gedafa, Ph.D., P.E., ENV SP
Chair and Associate Professor of Civil Engineering
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: **Letter of Commitment for Coal Bottom Ash Research Proposal**

Dear Dr. Gedafa:

MDU Resources Group, Inc., parent to Montana-Dakota Utilities Co. and Knife River Corporation, enthusiastically supports your research to determine the optimum coal bottom ash content for sustainable concrete infrastructure as outlined in the project summary that you shared with our team.

With a lignite coal-fired power plant site, a potential supplier of coal bottom ash, and Knife River, a potential user of coal bottom ash for use in their construction materials, we believe there is value in further exploring the use of coal bottom ash for cement and fine aggregate replacement in concrete if your research demonstrates enhanced concrete structure strength and durability when using coal bottom ash. Further, and especially for energy delivery and infrastructure-focused companies like ours, we believe your research results could increase sustainability, reduce the carbon footprint associated with manufacturing concrete, and improve economic benefits by enhancing commercial uses of coal bottom ash from landfills while reducing the use of other limited natural resources.

Montana-Dakota is committed to making available up to 500 pounds of coal bottom ash for your research and Knife River looks forward to reviewing the findings of your research as it relates to enhancing the strength and durability of concrete used in construction materials.

In closing, MDU Resources Group, along with Montana-Dakota and Knife River, is pleased to recommend this proposal for funding by the Lignite Research Council.

Sincerely,

Cory G. Fong
Director of Communications & Public Affairs
MDU Resources Group, Inc.

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5301 32nd Avenue South
Grand Forks, ND 58201

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March 19, 2021

Daba S. Gedafa, Ph.D., P.E., ENV SP
Chair and Associate Professor of Civil Engineering
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: Proposal to the Lignite Research Program Regarding "Research to Determine the Optimum Coal Bottom Ash Content for Sustainable Concrete Infrastructure"

Dear Dr. Gedafa:

Minnkota Power Cooperative, Inc. (Minnkota) is pleased to provide support for your effort to secure matching funds from the North Dakota Industrial Commission's Lignite Research Program for your research to determine the optimum coal bottom ash content for sustainable concrete infrastructure. The use of coal bottom ash as cement and fine aggregate replacement in concrete may result in structures that are stronger and more durable. It can also have environmental as well as economic benefits through diversion of coal bottom ash from landfills and reduced use of limited natural resources.

Minnkota is a not-for-profit electric generation and transmission cooperative headquartered in Grand Forks, ND. Formed in 1940, Minnkota provides wholesale electric energy to 11 member-owner distribution cooperatives located in eastern North Dakota and northwestern Minnesota. The primary source of electric generation for the Minnkota member-owners is the Milton R. Young Station (MRYS), a two-unit, lignite coal-fired power plant located near the town of Center, ND.

As such, Minnkota is committed to provide up to 500 lbs. of coal bottom ash needed for the research.

Given the practical nature of this project and its applicability to lignite-fueled facilities in North Dakota, Minnkota is supportive of the project and recommends favorable consideration by the Lignite Research Council.

We look forward to seeing the developments from this project. If you have any questions or require additional information, please contact me at 701-794-7234 or at gpfau@minnkota.com.

Sincerely,

Gerry Pfau
Sr. Manager of Project Development

Cc: Scott Hopfauf
Craig Bleth
Tim Hagerott
Andy Freidt
Dylan Wolf

Coyote Station
6240 13th Street Southwest
PO Box 339
Beulah, North Dakota 58523-0339
701-873-2571
www.otpco.com

March 18, 2021

OTTER TAIL
POWER COMPANY

Daba S. Gedafa, Ph.D., P.E., ENV SP
Chair and Associate Professor of Civil Engineering
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: **Letter of Commitment for Your Research Proposal**

Dear Dr. Gedafa:

Coyote Station is supportive of your research to determine the optimum coal bottom ash content for sustainable concrete infrastructure. The use of coal bottom as cement and fine aggregate replacement in concrete may result in structures that are stronger and more durable. It can also have environmental as well as economic benefits through diversion of coal bottom ash from landfills and reduced use of limited natural resources. Coyote Station is committed to provide up to 500 pounds of coal bottom ash needed for the research and highly recommends this proposal for funding by Lignite Research Council.

Sincerely,

Brad Zimmerman
Plant Manager
bz/lg

BORAL
RESOURCES

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March 24, 2021

Daba S. Gedafa, Ph.D., P.E., ENV SP
Chair and Associate Professor of Civil Engineering
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: **Letter of Commitment for Your Research Proposal**

Dear Dr. Gedafa:

We are glad to provide this letter of support and collaboration towards your research to determine the optimum coal bottom ash content for sustainable concrete infrastructure. The use of coal bottom as cement and fine aggregate replacement in concrete may result in structures that are stronger and more durable. It can also have environmental as well as economic benefits through diversion of coal bottom ash from landfills and reduced use of limited natural resources.

Boral Limited is a multinational company manufacturing and supplying building and construction materials, and our Boral North America division has a national fly ash processing and distribution business. We are very interested in your project subject matter.

For this project, we are willing to commit to provide material samples of bottom ash as well as basic chemical and physical characterization data such as chemical composition, gradation, specific gravity, etc.

I am pleased to provide this letter of support. Boral will dedicate the resources needed to assist and guide the proposed research activities. We wish you great success in your application. Please do let me know in case of any questions.

Sincerely,

Rafic Minkara, Ph.D., P.E.
VP, Product and Business Development
rminkara@boral.com
(770) 330 - 0689

AGGREGATE
INDUSTRIES

March 30, 2021

Daba S. Gedafa, Ph.D., P.E., ENV SP
Chair and Associate Professor of Civil Engineering
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: **Letter of Commitment for Your Research Proposal**

Dear Dr. Gedafa:

Aggregate Industries is supportive of your research to determine the optimum coal bottom ash content for sustainable concrete infrastructure. The use of coal bottom as cement and fine aggregate replacement in concrete may result in structures that are stronger and more durable. Aggregate Industries will use coal bottom ash as a fine aggregate and/or cement replacement in concrete in cooperation with our clients if the research shows good performance. Aggregate Industries is committed to provide concrete mixture information and up to 1,000 pounds of raw materials for laboratory testing for a project from 2021 construction season. This commitment includes materials, labor and equipment. Aggregate Industries highly recommends this proposal for funding by Lignite Research Council.

Sincerely,

Justin Flack
Aggregate Industries

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March 23, 2021

Daba S. Gedafa, Ph.D., P.E., ENV SP
Chair and Associate Professor of Civil Engineering
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: **Letter of Commitment for Your Research Proposal**

Dear Dr. Gedafa:

Border States Paving Inc is supportive of your research to determine the optimum coal bottom ash content for sustainable concrete and roller compacted concrete (RCC) infrastructure. The use of coal bottom as cement and fine aggregate replacement in concrete and RCC may result in structures that are stronger and more durable. Border States Paving will use coal bottom ash as a fine aggregate and/or cement replacement in concrete and RCC pavements in cooperation with our clients if the research shows good performance. Border States Paving Inc is committed to provide concrete mixture information and up to 1,000 pounds of raw materials for laboratory testing for a project from 2021 construction season. This commitment includes materials, labor and equipment. Border States Paving Inc highly recommends this proposal for funding by Lignite Research Council.

Sincerely,

Korey Bender
Border States Paving, Inc.

March 18, 2021

Daba S. Gedafa, Ph.D., P.E., ENV SP
Chair and Associate Professor of Civil Engineering
University of North Dakota
Upson II Room 260A
243 Centennial Drive Stop 8115
Grand Forks, ND 58202-8115

Subject: **Letter of Commitment for Your Research Proposal**

Dear Dr. Gedafa:

Strata Corporation is supportive of your research to determine the optimum coal bottom ash content for sustainable concrete infrastructure. The use of coal bottom as cement and fine aggregate replacement in concrete may result in structures that are stronger and more durable. Strata Corporation will use coal bottom ash as a fine aggregate and/or cement replacement in concrete in cooperation with our clients if the research shows good performance. Strata Corporation is committed to provide concrete mixture information and up to 1,000 pounds of raw materials for laboratory testing for a project from 2021 construction season. This commitment includes materials, labor and equipment. Strata Corporation highly recommends this proposal for funding by Lignite Research Council.

Sincerely, Dale J

Name [redacted] STRATA CORPORATION
Title QC MANAGER AGGREGATE DIVISION

GILSON COMPANY, INC.
PO BOX 200, LEWIS CENTER, OHIO 43035-0200
PHONE: 800-444-1508 740-548-7298
FAX: 800-255-5314 740-548-5314
WEBSITE: globalgilson.com
FED ID# 31-0961077

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Quote Expiration Date	5/15/2021

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GRAND FORKS ND 58202-8115
USA

Ship To:

QTD TO: DABA GEDAFA
EM: daba.gedafa@engr.und.edu
QTD BY: LINDA FARMWALD X 833
EM: LFARMWALD@GILSONCO.COM

Customer PO #	Customer ID	User ID	Shipping Method	Payment Terms	Req Ship Date	Master No.
	UNI-041602	lfarmwald		Net 30	0/0/0000	441,427

Quantity	Item Number	Description	UOM		Unit Price	Ext. Price
1	HM-345	Concrete Super Air Meter	EA		$3,200.00	$3,200.00
1	HMA-482	CAPE Tank for Super Air Meter ****FREE GROUND SHIPPING APPLIES WHEN ALL ITEMS ARE PURCHASED, EST LEAD TIME 7-10 DAYS	EA		$650.00	$650.00

PLEASE VERIFY THAT ALL ITEMS ARE CORRECT, REF: QUOTE #, SALES ORDER # IF MAKING ANY CHANGES. CONTACT: LINDA FARMWALD-WRIGHT X 833

Linda Farmwald

Subtotal	$3,850.00
Misc	$0.00
Shipping & Handling	$0.00
Tax	$0.00
Total	$3,850.00

GILSON COMPANY, INC.

Quote	Q076221
Date	3/16/2021
Page	1
Quote Expiration Date	5/15/2021

PO BOX 200, LEWIS CENTER, OHIO 43035-0200
PHONE: 800-444-1508 740-548-7298
FAX: 800-255-5314 740-548-5314
WEBSITE: globalgilson.com
FED ID# 31-0961077

DRAFT

Bill To:

UNIVERSITY OF NORTH DAKOTA
UPSON BLDG II ROOM 260
243 CENTENNIAL DRIVE STOP 8115
GRAND FORKS ND 58202-8115
USA

Ship To:

QTD TO: DABA GEDAFA
EM; daba.gedafa@engr.und.edu
QTD BY: LINDA FARMWALD, X 833
EM: LFARMWALD@GILSONCO.COM

Customer PO #	Customer ID	User ID	Shipping Method	Payment Terms	Req Ship Date	Master No.
	UNI-041602	lfarmwald		Net 30	0/0/0000	441,426

Quantity	Item Number	Description	UOM		Unit Price	Ext. Price
1	HM-723	Proove'it Permeability Tester Controller, 115V/60	EA		$7,900.00	$7,900.00
1	HMA-278	Rapid Chloride Permeability Cell 4in	EA		$890.00	$890.00
1	HMA-279	Sealing Ring for 100mm Specimens	EA		$45.00	$45.00
1	HMA-299	Verification Unit	EA		$1,800.00	$1,800.00
1	HMA-283	Standard Vacuum Chamber (4 to 6 Specimens)	EA		$850.00	$850.00
1	HMA-284	Standard Vacuum Pump for HMA-283	EA		$730.00	$730.00
1	HMA-286	Large Vacuum Chamber (Up to 20 Specimens)	EA		$2,900.00	$2,900.00
1	HMA-287	Large Vacuum Pump for HMA-286	EA		$995.00	$995.00
		**********************				
		PLEASE LET ME KNOW WHICH ITEMS YOU NEED,AS YOU WILL NOT NEED ALL ITEMS LISTED.				
		THIS DOES NOT INCLUDED SHIPPING , TO BE DETERMINED ON THE FINAL QUOTE.				

Subtotal	$16,110.00
Misc	$0.00
Shipping & Handling	$0.00
Tax	$0.00
Total	$16,110.00

PLEASE VERIFY THAT ALL ITEMS ARE CORRECT, REF: QUOTE #, SALES ORDER # IF MAKING ANY CHANGES. CONTACT: LINDA FARMWALD-WRIGHT X 833

Linda Farmwald