KTC

KENTUCKY TRANSPORTATION CENTER

**DEVELOPING A BYPRODUCT MATERIALS
INFORMATION SYSTEMS FOR THE
KENTUCKY TRANSPORTATION CABINET**

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Developing a Byproduct Materials Information System for the Kentucky Transportation Cabinet

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in cooperation with
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16. Abstract

Kentucky has numerous coal-fired, electric generating facilities and, as a result, there are abundant byproduct materials being produced from these facilities that have environmental, engineering, and economic potential as materials for use in common highway construction and maintenance related activities throughout the Commonwealth. Other byproduct materials are being produced and are available that may have potential uses as well. Although large quantities of byproduct materials are produced in Kentucky and many of those materials have positive or neutral environmental impacts and excellent engineering properties, a formal regulatory framework for selecting, characterizing, recovering, and recycling these material types does not exist. Fundamentally, the lack of a regulatory protocol is an obstacle to recycling byproducts and discourages the use of byproduct materials by the Kentucky Transportation Cabinet.

During this research effort, a byproduct materials information system was developed to guide the selection and use of ponded ashes in highway construction and maintenance activities. The information system was designed to be modular so that additional recovered and recyclable materials could be included within the matrices as these materials are evaluated at some future date. It is fully anticipated that the byproduct information system eventually will encompass any recovered or recycled materials that are shown through the prescribed method of evaluation to possess satisfactory environmental, engineering and economic characteristics that make them suitable for use in highway construction and maintenance activities.

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EXECUTIVE SUMMARY

The Kentucky Transportation Cabinet (KyTC) recognizes the potential for the use of byproduct materials in their mission. However, procedures are needed to fully characterize the environmental, engineering and economic impacts of the use of byproduct materials in construction and maintenance activities in order to avoid any potential for undesirable environmental, engineering or economic concerns during their application, or during or after their intended use. The purpose of this study was to develop and design a dynamic byproduct information system that would contain specific chemical, physical, and mechanical properties of Kentucky's abundant byproduct material sources to guide the selection and use of byproduct materials in highway construction and maintenance activities. For example, millions of tons of fly ash and bottom ash are produced each year from coal-fired power plants in Kentucky. These materials have highly desirable engineering properties that make them quite suitable for constructing highway embankments or other geotechnical structures. Using these materials in lieu of natural materials can provide large cost savings, especially in "borrow" fill situations. The byproduct information system was designed to be modular so that additional recovered and recyclable materials could be included within the matrices as these materials are evaluated at some future date. It is fully anticipated that the byproduct information system eventually will encompass any recovered or recycled materials that are shown through the prescribed method of evaluation to possess satisfactory environmental, engineering and economic characteristics that make them suitable for use in highway construction and maintenance activities.

The result of this research effort is the Kentucky Transportation Cabinet Byproduct Information System, or KyTCBIS. The purpose of the KyTCBIS is to develop a framework that allows highway construction and maintenance personnel to assess the practicality of using byproducts produced within Kentucky for their projects. The KyTCBIS implements a web application, which shows end users of the information system the various byproducts produced in different areas within Kentucky, the locations of the materials, along with their environmental and engineering properties. The KyTCBIS contains recommended applications for the byproducts and various tests performed to prove that these byproducts can be efficiently and effectively reused. There remains much to be done to make the KyTCBIS a complete, dynamic information system for the Kentucky Transportation Cabinet, producers of byproduct materials, and construction contractors.

Each byproduct producer within Kentucky should be contacted to gage and develop their interest in using the KyTCBIS. By encouraging byproduct materials producers to populate KyTCBIS with environmental and engineering property data, this information will be available statewide to Kentucky Transportation Cabinet personnel. Techniques were built into the KyTCBIS that will make it easy for producers to upload and manage their information. Screen cast, or videos, need to be developed that would completely illustrate how to use all functions in the KyTCBIS. This video stream should be added to the system for self help. Informal meetings with material producers will be needed to introduce them to the KyTCBIS and get some feedback on ways to improve the information system. Graphical functions need to be added to the KyTCBIS so that certain chemical properties, such as a given type and amount of a selected heavy metal, can be

graphed as a function of time and any changes in these properties could be readily discernable to the product users.

Further, efforts should be reinitiated to work with the University of Kentucky Center for Applied Energy Research (CAER) to access vital chemical data routinely collected by the CAER. The CAER collects samples from each coal-fired power plant every five years and performs chemical tests on those collected samples. Those data would be very useful for populating the KyTCBIS, which would provide a "centralized" source of chemical data for coal combustion products produced in Kentucky.

Specific site and related performance data where fly ash and bottom ash have been used at highway sites, as well as building sites, should be collected and added to the KyTCBIS. This effort would ultimately provide the documentation that fly ash and bottom ash has been used successfully at many engineering sites in Kentucky. Collecting and compiling case studies of sites where these materials have been used would aid in supporting the economical use of the byproducts at new construction sites.

1.0 Introduction and Background

Kentucky has numerous coal-fired, electric generating facilities and, as a result, there are abundant byproduct materials being produced from these facilities that have environmental, engineering, and economic potential as materials for use in common highway construction and maintenance related activities throughout the Commonwealth. Industrial byproducts, recovered, and recycled materials that have suitable environmental, engineering, and economic properties have been successfully used in several highway construction and maintenance activities throughout Kentucky and the world. For instance fly ash, bottom ash, lime kiln dust (a hydrated lime byproduct), steel slag, shredded tires, glass, and even cinders have been used successfully during some facet of highway construction and maintenance from the pavement surface to embankment construction to landslide correction (see Figure 1).

Research Report KTC-93-18, Utilization of Fossil-Fuel Related By-Product Materials for Highway Construction in Kentucky detailed the Kentucky Transportation Cabinet's Department of Highways' efforts during the 1980's and into the early 1990's to use byproduct materials produced within the state in various construction activities. Some of the recovered materials used and described in this report include bottom ashes, ponded fly ash, scrubber sludge, and residues from two distinctly different atmospheric fluidized bed combustion processes. These materials were used in applications such as embankment construction, stabilized subbases and subgrades, and as an aggregate replacement in an asphaltic concrete surface course. Based upon the results of

Figure 1. Bottom ash from a coal-fired electric power plant used in a landslide correction in McCreary County, Kentucky.

various field trial applications conducted during the research period, the researchers concluded that some byproduct materials were very well suited for highway construction applications. Particularly successful were the field trials involving the use of scrubber sludge in a pavement subbase layer and as an embankment fill material, the use of multi-cone kiln dust as a soil subgrade modifier, and the use of ponded fly ash in lieu of specification fly ash in a stabilized aggregate base layer. Researchers recommended that future uses of byproduct materials be implemented by the Department of Highways where promising and feasible. The specifications developed during the research study for design and construction procedures for the use of byproduct materials in pavement structures were deemed to be practical approaches to the applications implemented.

More recently, fly ash materials were used successfully for embankment construction during the construction of the Winchester Bypass in Clark County and in the connector route from KY 33 to US 62 in Woodford County. Other byproduct materials are being produced and are available that may have potential uses as well. Although large quantities of byproduct materials are produced in Kentucky and many of these materials have positive or neutral environmental

impacts and excellent engineering properties, a formal regulatory framework for selecting, characterizing, recovering, and recycling these material types does not presently exist. Fundamentally, the lack of a regulatory protocol is an obstacle to recycling byproducts and discourages the use of byproduct materials by the Kentucky Transportation Cabinet. The Kentucky Transportation Cabinet (KyTC) recognizes the potential for the use of byproduct materials in their mission but should have procedures in place to fully characterize the environmental, engineering and economic impacts of the use of byproduct materials in construction and maintenance activities. Any potential for undesirable environmental, engineering or economic concerns during their application, or during or after their intended use must be avoided. Therefore, the KyTC needs an information resource to guide the selection and use of byproduct materials in highway construction and maintenance projects.

2.0 Overview of Project History and Study Objectives

The idea for this research effort was approved during research focus group meetings by the Kentucky Transportation Cabinet and budgeted as a three-year program beginning in Fiscal Year 2005. The originally drafted work plan was entitled "Development of a Byproduct Resource Manual and Database for Highway Applications in Kentucky." However, after numerous meetings of the Study Advisory Committee and several revisions of the proposal, the work plan was not approved during the first year of the study. Therefore, very little progress on the research study was made during the first year and, in fact, it was nearly the end of the second year of the three-year study before the research plan of work was approved by the Study Advisory Committee. The work plan approval was preceded by changes in research personnel and renewed efforts to address perceived deficiencies within the original work plan related to environmental concerns stemming from the possible use of byproduct materials in highway applications.

The revised work plan for the research project retained most of the original proposal but included an increased emphasis on the chemical properties of the byproduct materials, defining changes in the chemical properties over time, and both the natural and human environmental impacts of utilizing byproduct materials in highway construction and maintenance applications throughout the Commonwealth of Kentucky. The final version of the work plan also increased the responsibility of the byproduct material suppliers to provide any available documentation relative to the physical and chemical properties of the materials being produced at their facilities. Time and monetary constraints placed on the research team after achieving approval of the plan of work for the research effort effectively reduced the scope of the study to developing the framework for an information system that could be used to guide highway engineers in the selection, characterization and application of byproduct materials in highway construction and maintenance activities. A dynamic byproduct information system was designed to contain geographic locations of the material sources, historical specifics of the materials including any chemical, physical and mechanical properties of the byproduct material resources developed over time, test methods that are used to evaluate the materials for application design, and both long-term and short-term performance measures for the applications wherein byproduct materials have been used.

The efforts of this study were limited to developing the framework only for fly ash and bottom ash materials throughout Kentucky that could be recoverable from coal-fired electric generation plants. However, the byproduct information system was designed to be modular so that additional recovered and recyclable materials could be included within the matrices as these materials are evaluated at some future date. It is fully anticipated that the byproduct information system eventually could encompass any recovered or recycled materials that are shown through the prescribed method of evaluation to possess satisfactory environmental, engineering and economic characteristics that make them acceptable for use in highway construction and maintenance projects.

The basic criteria for considering a byproduct material for inclusion within this study were based on a review of:

- Chemical properties—very toxic, hazardous materials will not be considered for use but would be included in the information system and designated for non-use.
- Physical properties—the material to be included in the information system must have some potential for use in a highway application.
- Quantity—materials that are not produced in significant quantities were not given priority in this study.
- Location—byproduct materials that are located in remote areas and would require long-haul distances were not be given high priority in this study.

The byproduct information system was developed based upon a review of available literature on the use of byproduct materials in highway construction and maintenance projects. It was largely patterned after a static database developed by the University of New Hampshire under a grant by the Federal Highway Administration (FHWA). The literature review also provided information about how byproducts have previously been used in highway applications in Kentucky and other states, the selection and characterization of the byproduct materials used, and the performance of the applications relative to the byproduct material's environmental, engineering, and economic qualities. Tests and criteria for the use of byproduct materials have been specified to ensure that any material considered for use would meet applicable engineering, environmental, and occupational health and safety standards.

The byproduct information system was designed to contain details of the tests necessary to define the environmental and engineering properties of byproduct materials. The standard test methods, or modified methods that are used for analyses to define criteria for acceptance of the materials for a particular use, would be included in the byproduct information system. The applicable standard test methods of the American Association of State Highway and Transportation Officials (AASHTO), American Society for Testing and Materials (ASTM) and appropriate Kentucky Standard Test Methods will be identified in the byproduct information system. Any modifications to the standard test methods or required supplemental laboratory tests can also be detailed.

The completed byproduct information system will contain references to specific types of tests, analyses, and criteria necessary to characterize a material for a particular application design. Criteria for environmental characterization and acceptance for various uses, including test

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methods (field and laboratory), frequency of testing and acceptable contaminant concentrations, will be included. Criteria established will consider both potential for impact to the natural environment as well as health and safety issues related to potential human contact with the material. Results from laboratory tests, field tests, or other assessment procedures detailed within the byproduct information system will make it possible to determine if a reuse of the material in a highway construction or maintenance application will result in any possible adverse environmental, engineering, or occupational health and safety impacts.

The completed byproduct information system may also address other intangible, non-technical implementation factors that must be considered even if all of the environmental, engineering, occupational health and safety, recyclability and economic issues for the use of a material are satisfactorily addressed. These non-technical factors include institutional, political and public acceptability of reusing a specific material. Institutional acceptability is a factor that accounts for all of the steps that will be necessary to gain acceptance of a material. Political acceptability includes the expected level of support from public officials for the proposed use of the byproduct material and public acceptability is a factor that must be considered in any process.

A survey of bottom ash and fly ash producers within Kentucky was conducted to inform them of the objective of this effort and to determine if they desired to have their recoverable byproduct materials considered for inclusion in the byproduct information system. In the initial stages the study focused on identifying locations where byproduct materials are produced or stored in large quantities. The potential supplier was asked to thoroughly describe the processes that have been historically used to produce the materials. A complete history of the processes that produced the materials being considered for re-use, including an analysis of how process changes may have resulted in variation in the chemical properties of the material, was required. It was requested that material managers describe each byproduct material produced relative to its origin, management history of the source, changes in raw materials, other possible market sources, and general uses. Available analytical data, both chemical and physical, were also requested. Material safety data sheets were requested from the producer for inclusion in the byproduct information system. Potential suppliers were also asked to define distances within which they believed that hauling costs would be offset by disposal cost savings (i.e. no net cost for the byproduct material) and maximum hauling distances in which material usage remained economical. Data were to be assimilated and normalized to define geographic Cost Effective Use Zones within which usage of the byproduct material appears viable.

A limited amount of field reconnaissance was conducted to document the locations and condition of the byproduct material sources. Specifically, two electrical power producing plants were visited. On-site interviews were conducted with plant representatives regarding process changes, historic handling of materials, past and current storage and management practices, and to obtain past chemical and physical analytical data. The sources designated by the materials producers were located and photographed for future reference. Kentucky Transportation Center personnel also contacted the University of Kentucky's Center for Applied Energy Research (CAER) to gather historical information derived from surveys conducted by the CAER to document coal ash characteristics.

Chemical properties of the materials, TCLP (Toxicity Characteristic Leaching Procedure) information and results from the Distilled Water Leaching procedure, if available, were expected to be obtained from the materials producers or from other agencies. The data proposed to be contained within the byproduct information system will enable statistical analysis of the chemical properties of the materials to be performed to evaluate the variation of different types of chemicals or trace metals within those byproducts. Similar assessments may be made of other byproducts when the data become available.

3.0 Literature Review

Several resources have been developed through the Federal Highway Administration (FHWA) that provide invaluable guidance to highway agencies for the use of byproduct materials in highway construction. One resource is titled "User Guidelines for Waste and Byproduct Materials in Pavement Construction," Research Report FHWA-RD-97-148. This document is a major compilation of efforts in the area of utilizing waste and byproduct materials in highway construction applications and provides information about the use of 19 different waste and byproduct materials in six major highway applications. Each material is described (origin, current management options, market sources, and general uses). The document also establishes conceptual evaluation guidance issues (framework, environmental, costs) and describes the six major highway applications. The second resource is a static database that was developed as the result of work sponsored by AASHTO, in cooperation with the FHWA, and conducted under the auspices of the National Highway Cooperative Research Program (NCHRP), which is administered by the Transportation Research Board of the National Research Council. The static database developed under research project NCHRP 4-21 contains information on 21 waste and recycled materials. Information includes photographs of the materials, general information for various recyclable materials, production and use data, environmental and engineering properties data, suitable highway applications, laboratory testing requirements, field-testing, references and points of contact within state highway agencies. A third resource, "Framework for Evaluating Use of Recycled Materials in the Highway Environment" is a follow-on to the User Guidelines and NCHRP 4-21 projects and provides a consensus framework for state transportation and environmental regulators to evaluate the prospective use of recycled materials in the highway environment. A logical framework is provided for issues of identification, preliminary screening, laboratory testing, and field-testing stages. A variety of approval and material modification steps are also offered. Extensive test methods and applicable standards or criteria (both materials and environmental) are given for the laboratory and field-testing stages. This work was funded by cooperative agreement DTFH61-97-X-00020 to the University of New Hampshire from the FHWA.

The following is a summary of the material descriptions, engineering and environmental properties, and uses of fly ash and bottom ash materials in highway construction and maintenance activities. These uses have proven the effectiveness and economics of recycling and using byproduct materials produced from coal-burning power plants in highway construction and maintenance applications.

3.1 General Information for Fly Ash

Coal fly ash is a fine-grained, powdery-like material that is collected in the air pollution control system of coal-fired (pulverized coal) power plants. Fly ash that is produced from the combustion of anthracite or bituminous coal tends to exhibit pozzolanic properties. These pozzolanic fly ashes (if they are of specified size and purity) are sometimes referred to as Class F fly ash. Fly ash that is produced from the burning of lignite or sub-bituminous coal tends to be self-cementing. These fly ashes are sometimes referred to as Class C fly ash. Fly ash to be used in Portland cement concrete (PCC) must meet the requirements of ASTM C618. The two classes of fly ash are defined in ASTM C618.

During 2006 there was approximately 72.5 million tons of coal fly ash produced in the United States. Of this amount, approximately 45 percent was used in construction or other applications. Fly ash used in concrete, concrete products, cement, structural fills and soil modification accounted for about 83% of the approximately 27 million tons of coal fly used in 2006.

3.1.1 Engineering Properties of Fly Ash

3.1.1.1 Physical Properties

Depending upon the proposed beneficial reuse of fly ash, the most commonly identified physical properties are particle shape, specific surface area, specific gravity, density, fineness, gradation, and moisture content. Fly ash consists of fine powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. The carbonaceous material in fly ash is composed of angular particles. The Blaine air permeability test, which is commonly used for Portland cement concrete, is a measure of the specific surface area of a material. Values of Blaine fineness for fly ash range typically from 1,700 to 10,000 cm^2/gram. The specific gravity of fly ash tends to be in a range from 2.0 to 2.8, but may be as low as 1.7 and as high as 3.0. Fly ash has a relatively low compacted density. Typical compacted dry densities for fly ashes resulting from the burning of bituminous coal range from 800 - 1360 kg/m^3 (50 - 85 lbs/ft^3). Fineness (percent of material retained on a 0.045 mm or No. 325 sieve) is the characteristic of fly ash that influences its pozzolanic activity (reactivity with soluble calcium ions). ASTM C618 specifies that a Class F (pozzolanic) fly ash should have no more than 34 percent of the ash retained on a 0.045 mm (No. 325) sieve. The fineness of coal fly ash produced from the burning of bituminous coal tends to range from 15 to 45 percent retained on a No. 325 sieve. The particle size distribution of most sources of coal fly ash is generally similar to that of a silt with the major fraction of particles (60 to 90 percent) being finer than 0.075 mm (No. 200 sieve). Fly ash particles are normally sized from 1 to

100 microns. Fly ash can occur over a wide moisture content range. When dry, fly ash is cohesionless and can be quite dusty. When saturated, fly ash is difficult to handle and manage. But, as with most fine-grained soils, fly ash can be readily handled and compacted at intermediate moisture contents, and will generally exhibit some cohesion.

Other commonly identified physical properties, depending upon the proposed use, are dry unit weight, plasticity, absorption, soil classification and sand equivalent value.

3.1.1.2 Chemical Properties

The chemical properties of fly ash are influenced to a great extent by the type of coal burned (anthracite, bituminous, sub-bituminous, and lignite) and the techniques used for handling and storage (dry, conditioned, or wet form). The principal components of bituminous coal fly ash are silica (20-60%), alumina (5-35%), iron oxide (10-40%), and calcium, with varying amounts of carbon, as measured by the loss on ignition (LOI). In bituminous coal fly ash, total calcium typically ranges from 1 to 12 percent, mostly in the form of calcium hydroxide, calcium sulfate, and glassy components in combination with silica and alumina. The loss on ignition (LOI), which is a measurement of the amount of unburned carbon remaining in the fly ash, is one of the most significant chemical properties of fly ash, especially as an indicator for its suitability for use as a cement replacement in concrete. The LOI for fly ash that results from the burning of bituminous coal ranges from 0 to 15 percent.

The chief difference between Class F and Class C fly ash is in the amount of calcium and the silica, alumina, and iron content in the ash. In Class F fly ash, total calcium typically ranges from 1 to 12 percent, mostly in the form of calcium hydroxide, calcium sulfate, and glassy components in combination with silica and alumina. In contrast, Class C fly ash may have reported calcium oxide contents as high as 30 to 40 percent. Another difference between Class F and Class C is that the amount of alkalis (combined sodium and potassium) and sulfates (SO_4) are generally higher in the Class C fly ashes than in the Class F fly ashes.

3.1.1.3 Mechanical Properties

The most commonly evaluated mechanical properties of fly ash are shear strength, bearing strength and permeability. Fly ash derives most of its shear strength from internal friction. In bituminous coal fly ash, the angle of internal friction typically ranges from 26 to 42 degrees. California Bearing Ratio (CBR) values vary and are dependent on the type of ash and the specific manner in which the CBR test is conducted. Fly ash samples resulting from the burning of bituminous coals have been found to exhibit

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CBR values in the range of silts and clays. Reported California Bearing Ratio data for fly ash produced from the burning of bituminous coal range from 10.8 to 15.4% (unsoaked) and 6.8 to 13.5% (soaked). The permeability of well-compacted fly ash from bituminous coals has been found to be similar to that of a silty sand to silty clay soil, 1.2 E-03 to 3.2 x 10E-5 cm/sec. Other mechanical properties to determine for design purposes include maximum dry density and optimum moisture content.

3.1.2 Environmental Properties of Fly Ash

The major environmental concern associated with the use of fly ash in construction applications is the presence and solubility of trace metals such as arsenic and chromium in the ash. When used as a supplementary cementitious material, mineral filler, or in flowable fill applications, due to the alkaline environment, the percentage of fly ash used in a structure, and the encapsulated or bound nature of the product, such concerns are unwarranted.

When fly ash is used or proposed for use as an embankment or fill material, then water solubility and fugitive dust issues are more prominent. Solubility of trace metals in the fly ash is in great part dependent on the alkalinity and pH of the fly ash, which can vary from acidic to alkaline depending on the source of the ash. The alkalinity or acidity is dependent in great part on the ratio of calcium and magnesium oxides to sulfates and aluminum oxide present in the ash. In assessing fly ash leachability it is necessary to examine each fly ash source independently.

While trace metal solubility will depend for the most part on the pH and alkalinity of the liquid environment, high total dissolved solids, calcium, and sulfates will leach from coal fly ash. A high salt level associated with fly ash is a consideration that should be addressed if fly ash is proposed for use over sensitive ground waters.

Fugitive dust emission issues can be mitigated in most cases by ensuring that the fly ash is moisture conditioned prior to use and that fly ash embankments or fills are capped with an overburden soil.

The main components of coal fly ash are aluminum (Al), calcium (Ca), iron (Fe), and silica (Si). The trace metal concentrations in coal fly ash are dependent on the source material. Relatively high concentrations of arsenic, barium, beryllium, cadmium, chromium, lead, mercury, selenium, and vanadium may be found in some fly ashes.

Due to the nature of the material and the temperatures the coal is exposed to during combustion, significant levels of trace organics would not be expected in coal fly ash.

For the samples tested, all reported trace organic leachate concentrations were below the USEPA hazardous waste criteria. While in the majority of cases trace metal concentrations were below USEPA hazardous waste criteria, in some instances arsenic (As) and chromium (Cr) concentrations were reported to exceed USEPA hazardous waste criteria.

3.1.3 Potential Highway Uses and Processing Requirements of Fly Ash

Fly ash is useful in many applications because it is a pozzolan, meaning it is a siliceous or alumino-siliceous material that, when in a finely divided form and in the presence of water, will combine with calcium hydroxide (from lime, Portland cement, or kiln dust) to form cementitious compounds.

3.1.3.1 Portland Cement Concrete – Supplementary Cementitious Material

Fly ash has been successfully used as a mineral admixture in PCC for nearly 60 years. This is the largest single use of fly ash. Fly ash must be in a dry form when used as a mineral admixture. Fly ash quality must be closely monitored when the material is used in PCC. The principal benefits ascribed to the use of fly ash in concrete include enhanced workability due to spherical fly ash particles, reduced bleeding and less water demand, increased ultimate strength, reduced permeability and chloride ion penetration, lower heat of hydration, greater resistance to sulfate attack, greater resistance to alkali-aggregate reactivity, and reduced drying shrinkage. The main precautions usually associated with the use of fly ash in concrete include somewhat slower early strength development, extended initial setting time, possible difficulty in controlling air content, seasonal limitations during winter months, and quality control of fly ash sources. The net result of all these restrictions is that only a relatively low percentage (25 to 30 percent, at most) of all the coal fly ash produced annually is even potentially suitable for use in Portland cement concrete.

When fly ash is used as a mineral admixture, the ready-mix producer typically handles fly ash in the same manner as Portland cement, except that fly ash must be stored in a separate silo from the Portland cement.

Certain fly ashes will reduce the effectiveness of air entraining agents, requiring a higher dosage to meet specifications. Therefore, the concrete producer must assure that the proper amount of air entraining admixture is added during mixing, so that the air content of the concrete is within specified limits.

Placement and handling of fly ash concrete is in most respects similar to that of normal concrete. Fly ash concrete using Class F fly ash has a slower setting time than normal concrete. As a result, finishing operations

may have to be delayed, possibly by one up to two hours, depending on the temperature. Also, fly ash concrete surfaces may tend to be stickier than normal concrete during placement and finishing, although properly proportioned concrete mixes containing fly ash should benefit workability and finishing. Normal procedures for screeding, finishing, edging and jointing of conventional Portland cement concrete are also applicable to fly ash concrete.

3.1.3.2 Asphalt Concrete – Mineral Filler

Fly ash has been used as substitute mineral filler in asphalt paving mixtures for many years. Mineral filler in asphalt paving mixtures consists of particles, less than 0.075 mm (No. 200 sieve) in size, that fill the voids in a paving mix and serve to improve the cohesion of the binder (asphalt cement) and the stability of the mixture. The mix design methods that are commonly used for hot mix asphalt paving mixtures are also applicable to mixes in which coal fly ash is introduced as mineral filler. There are few states that make specific reference to coal fly ash as a mineral filler substitute. Mineral filler property specifications are contained in AASHTO M17.

Most fly ash sources are capable of meeting the gradation (minus .075 mm) requirements and other pertinent physical (nonplastic) and chemical (organic content) requirements of mineral filler specifications. Fly ash must be in a dry form for use as mineral filler. Fly ash that is collected dry and stored in silos requires no additional processing. It is possible that some sources of fly ash that have a high lime (CaO) content may also be useful as an antistripping agent in asphalt paving mixes.

Research conducted over many years has determined that fly ash is a suitable mineral filler material. Fly ash (depending on the sources) has been shown to have comparable physical properties to limestone dust, to possess good void filling characteristics, and to be hydrophobic, meaning it sheds water easily, thus reducing the potential for asphalt stripping. Although most fly ash sources are capable of satisfying specification requirements for asphalt mineral filler, which relate mostly to particle sizing, not all fly ashes have performed satisfactorily in asphalt paving mixtures. The reasons for this are not altogether clear, but are probably related to the fineness of the fly ash, its chemical composition, and its affinity for the asphalt cement used in a paving mix. A better means of classifying fly ash for use as mineral filler is needed. The calcium content, and in particular the free or available lime (CaO) content, of fly ash with a high calcium content is believed to be instrumental in its performance as a filler, especially as an aid in the prevention of asphalt stripping. Additional field performance data are needed to draw valid conclusions regarding these factors.

3.1.3.3 Stabilized Base – Supplementary Cementitious Material

Stabilized bases or subbases are mixtures of aggregates and binders, such as Portland cement, which increase the strength, bearing capacity, and durability of a pavement substructure. Because fly ash may exhibit pozzolanic properties, or self-cementing properties, or both, it can and has been successfully used as part of the binder in stabilized base construction applications. When pozzolanic-type fly ash is used, an activator must be added to initiate the pozzolanic reaction. The most commonly used activators or chemical binders in pozzolan-stabilized base (PSB) mixtures are lime and Portland cement, although cement kiln dusts and lime kiln dusts have also been used with varying degrees of success. Sometimes, combinations of lime, Portland cement, or kiln dusts have also been used in PSB mixtures. The successful performance of PSB mixtures depends on the development of strength within the matrix formed by the pozzolanic reaction between the fly ash and the activator. This cementitious matrix acts as a binder that holds the aggregate particles together, similar in many respects to a low-strength concrete.

If the fly ash to be used in a pozzolanic stabilized base mixture is to be mixed in a dry form, the fly ash must be stored in a silo or pneumatic tanker until it is ready for use. If conditioned fly ash (usually Class F fly ash) is to be used, then the conditioned fly ash can be stockpiled until it is ready to be used. If fly ash is stockpiled for an extended period in dry or windy weather conditions, the stockpile may need to periodically be moistened to prevent unwanted dusting.

The blending or mixing of pozzolanic stabilized base materials can be accomplished either in a mixing plant or in-place. Plant mixing is recommended because it provides greater control over the quantities of materials batched, and it also results in the production of a more uniform pozzolanic stabilized base mixture.

Plant-mixed materials should not be stockpiled, but should be delivered to the job site as soon as possible after mixing. Compaction of pozzolanic stabilized base materials should be completed as quickly as possible after placement, especially with mixtures containing Class C (self-cementing) fly ash.

After placement and compaction of the stabilized base pozzolanic material, it must be properly cured to protect against drying and to assist in the development of in-place strength. If an asphalt concrete pavement is to be placed as an overlay, an asphalt emulsion seal coat should be applied to the top surface of the base or subbase within 24 hours or less of placement. The exact type of emulsion, rate of application, and

temperature of the asphalt must be in compliance with applicable specifications.

3.1.3.4 Flowable Fill – Aggregate or Supplementary Cementitious Material

Flowable fill is a slurry mixture consisting of sand or other fine aggregate material and a cementitious binder that is normally used as substitute for a compacted earth backfill. Fly ash has been used in flowable fill applications as a fine aggregate and (because of its pozzolanic properties) as a supplement to or replacement for the cement. Either pozzolanic or self-cementing fly ash can be used in flowable fill. When large quantities of pozzolanic fly ash are added, the fly ash can act as both fine aggregate and part of the cementitious matrix. Self-cementing fly ash is used in smaller quantities as part of the binder in place of cement. The quality of fly ash used in flowable fill applications need not be as strictly controlled as in other cementitious applications. Both dry and reclaimed ash from settling ponds can be used. No special processing of fly ash is required prior to use.

Most state transportation agencies have used flowable fill mainly as a trench backfill for storm drainage and utility lines on street and highway projects. Flowable fill has also been used to backfill abutments and retaining walls, fill abandoned pipelines and utility vaults, fill cavities and settled areas, and help to convert abandoned bridges into culverts. Although most states have somewhat limited experience to date with flowable fill, nearly all states that have used the material have thus far indicated satisfactory performance with little or no problems. Since flowable fill is normally a comparatively low strength material, there are no strict quality requirements for fly ash used in flowable fill or Controlled Low-Strength Material (CLSM) mixtures. Fly ash is well suited for use in flowable fill mixtures. Its fine particle sizing (non-plastic silt) and spherical particle shape enhances mix flowability. Its relatively low dry unit weight (usually in the 890 to 1300 kg/cu m (55 to 80 lb/cu ft) range) assists in producing a relatively lightweight fill, and its pozzolanic or cementitious properties provide for lower cement requirements than would normally be required to achieve equivalent strengths.

If the fly ash is used in a flowable fill mixture and mixed in a dry form (usually in low fly ash content mixes), the fly ash must be stored in a silo or pneumatic tanker until it is ready for use. Fly ash (usually Class F fly ash) that is to be used in a conditioned form in high fly ash content mixes can be stockpiled until it is ready to be used. Flowable fill materials can be batched and mixed in pugmills, turbine mixers or central-mix concrete plants. Flowable fill materials are most commonly transported to the site and discharged using ready-mix concrete trucks. However, flowable fill

may also be placed by means of pumps, conveyors, chutes, boxes, buckets, tremie, or in any way that concrete can be placed. Flowable fill materials require no compaction or vibration following placement.

For placement of relatively deep backfills behind abutments or retaining walls, several lifts or layers are recommended. This limits the amount of lateral pressure exerted by the flowable fill at any one time and also prevents excessive heat of hydration, especially if self-cementing fly ash is used. When flowable fill is used to backfill pipe trenches, some lighter weight pipes, such as corrugated metal pipes, will have to be tied down or in some way restrained to prevent them from floating as the flowable fill is being placed.

Flowable fill can be placed where water either flows or has accumulated and the flowable fill will displace the water, thus eliminating the need for pumping prior to placement. There are normally no requirements for the curing of flowable fill, although during periods of hot weather, it may be advisable to cover the exposed surfaces of flowable fills to minimize evaporation and the subsequent development of shrinkage cracking.

3.1.3.5 Embankment and Fill Material

Fly ash has been used for several decades as an embankment or structural fill material, particularly in Europe. There has been relatively limited use of fly ash as an embankment material in the United States, although its use in this application is becoming more widely accepted. As an embankment or fill material, fly ash is used as a substitute for natural soils. Fly ash in this application must be stockpiled and conditioned to its optimum moisture content to ensure that the material is not too dry and dusty or too wet and unmanageable. When fly ash is at or near its optimum moisture content, it can be compacted to its maximum density and will perform in an equivalent manner to well-compacted soil.

The minimum amount of construction equipment needed to properly place and compact fly ash in an embankment or structural backfill includes a bulldozer for spreading the material, a compactor, either a vibrating or pneumatic tired roller, a water truck, to provide water for compaction (if needed) and to control dusting, and a motor grader, where final grade control is critical.

Although very few of these projects have been monitored for long-term performance, none of the states in which these projects have been constructed have indicated any dissatisfaction or concern with the embankments or backfills constructed using fly ash in their states.

3.2 General Information for Coal Bottom Ash

The most common type of coal-burning furnace in the electric utility industry is the dry, bottom pulverized coal boiler. When pulverized coal is burned in a dry, bottom boiler, about 80 percent of the unburned material or ash is entrained in the flue gas and is captured and recovered as fly ash. The remaining 20 percent of the ash is dry bottom ash, a dark gray, granular, porous, predominantly sand size minus 12.7mm (½ in) material that is collected in a water-filled hopper at the bottom of the furnace. When a sufficient amount of bottom ash drops into the hopper, it is removed by means of high-pressure water jets and conveyed by sluiceways either to a disposal pond or to a decant basin for dewatering, crushing, and stockpiling for disposal or use. During 2006 there was approximately 18.5 million tons of bottom ash produced in the United States. Of this amount, approximately 45 percent was used in construction or other applications. Uses in structural fills and road bases, subbases, and bituminous pavement accounted for about 56% of the approximately 8.4 million tons of coal bottom ash used in 2006.

3.2.1 Engineering Properties of Bottom Ash

3.2.1.1 Physical Properties

Depending upon the proposed beneficial reuse of bottom ash, the most commonly identified physical properties are particle shape and texture, gradation, absorption, specific gravity, compacted density, and unit weight. Bottom ashes have angular particles with a very porous surface texture. Bottom ash particles range in size from a fine gravel to a fine sand and they have very low percentages of silt and clay-sized particles. The ash is usually a well-graded material, although variations in particle size distribution may be encountered in ash samples taken from the same power plant at different times. Bottom ash is predominantly sand-sized, usually with 50 to 90 percent passing a 4.75 mm (No. 4) sieve, 10 to 60 percent passing a 0.42 mm (No. 40) sieve, 0 to 10 percent passing a 0.075 mm (No. 200) sieve, and a top size usually ranging from 19 mm (3/4 in) to 38.1 mm (1-1/2 in). Bottom ash generally has somewhat higher absorption values than natural sand or limestone sand, which is usually in the 1 to 2 percent range.

The specific gravity of the dry bottom ash is a function of its chemical composition, with higher carbon content resulting in lower specific gravity. Bottom ash with a low specific gravity has a porous or vesicular texture, a characteristic of "popcorn" particles that readily degrade under loading or compaction. The specific gravity of most sources of bottom ash will range from 2.1 to 2.7. The compacted density of bottom ash generally varies from 1,200 - 1840 kg/m^3 (75 - 115 lbs/ft^3). The dry unit weight of bottom ash usually ranges from 720 to 1600 kg/m^3 (45 to 100 lb/ft^3). Bottom ash is lightweight material relative to conventional aggregate materials.

3.2.1.2 Chemical Properties

Bottom ash is composed principally of silica, alumina, and iron, with smaller percentages of calcium, magnesium, sulfates, and other compounds. The composition of the bottom ash particles is controlled primarily by the source of the coal and not by the type of furnace. Bottom ash derived from lignite or sub-bituminous coals have a higher percentage of calcium than the bottom ash or boiler slag from anthracite or bituminous coals. Sulfate is usually very low (less than 1.0 percent), unless pyrites have not been removed from the bottom ash.

Due to the salt content and, in some cases, the low pH of bottom ashes, these materials could exhibit corrosive properties. When using bottom ash in an embankment, backfill, subbase, or even possibly in a base course, the potential for corrosion of metal structures that may come in contact with the material is of concern and should be investigated prior to use. Corrosivity indicator tests normally used to evaluate bottom ash are pH, electrical resistivity, soluble chloride content, and soluble sulfate content. Materials are judged to be noncorrosive if the pH exceeds 5.5, the electrical resistivity is greater than 1,500 ohm-centimeters, the soluble chloride content is less than 200 parts per million (ppm), or the soluble sulfate content is less than 1,000 parts per million (ppm).

3.2.1.3 Mechanical Properties

The most commonly evaluated mechanical properties of bottom ash are bearing strength, shear strength, durability, particle strength, permeability, maximum dry density, and optimum moisture. California Bearing Ratio (CBR) values for bottom ash have been found to range from 40 to 70 percent, which are comparable to CBR values for high quality gravel base materials. Soaking of bottom ash samples has been found to increase the CBR values of bottom ash. These findings suggest that it may be advantageous to compact bottom ash in a "flushed" or wet condition. Reported friction angle values for bottom ash are within the same range as those for sand and other conventional fine aggregate sources, which are usually between 38 and 42 degrees. Direct shear tests conducted on dry bottom ash samples under loose and dense relative density conditions indicate that the angle of internal friction for most bottom ashes range from 35° to 50°, depending on the extent of densification, with some dense bottom ash samples exhibiting friction angles as high as 55°.

The sodium sulfate soundness loss for bottom ash tends to range from 1.5 to 10 percent. These values are generally found to be within ASTM D1073 weight loss specifications of not more than 15 percent after five cycles when sodium sulfate is used, or not more than 20 percent after five cycles when magnesium sulfate is used. In some power plants, coal

pyrites are disposed of with the bottom ash. In such cases, some pyrite or soluble sulfate can be contained in the bottom ash. This can result in reduced particle durability and higher sodium sulfate soundness loss values. The rather wide range of values reported may be indicative of the presence of pyrite in the samples. Bottom ash exhibits marginal durability as measured by the Los Angeles abrasion test with abrasion loss values between 30 and 50 percent. Most bottom ash samples have some friable particles that cause higher than normal abrasion loss values.

Bottom ashes exhibit values of coefficient of permeability within the range of 10^{-02} to 10^{-03} cm/sec. The permeability of bottom ash is related to the percentage of particle sizes finer than the minus 0.075 mm or U. S. Standard No. 200 sieve and is usually comparable to that of a well-graded sandy soil. The maximum dry density of bottom ash materials have been reported to range from 1,210 to 1,620 kg/m^3 (75 to 100 lb/ft^3). The optimum moisture content of bottom ash is usually below 20% and has been reported to range from 12 to 24%.

3.2.2 Environmental Properties of Bottom Ash

Coal bottom ash contains a variety of environmentally sensitive trace metals in relatively low concentrations (depending on the source) and a few trace organics of concern. Available data suggest that leaching of trace metals from coal bottom ash, particularly if used in bound (e.g., asphalt concrete) applications, would be of little concern. When used in unbound (e.g., granular base) applications, additional care would be warranted. Each bottom ash source should be evaluated to determine the trace leaching characteristics. Special provisions to control fugitive dust emissions must be considered if bottom ash is to be used. Dry bottom ash when handled can be expected to release fugitive dust.

The main components of coal bottom ash are aluminum (Al), calcium (Ca), iron (Fe), magnesium (Mg), and silica (Si). The trace metal composition of the ash is primarily a factor of the source material. Some coal bottom ash may contain relatively high barium and chromium levels.

The research presented show that all the trace organic concentration values reported were below method detection limits. Due to the nature of the material and the temperatures the coal is exposed to, significant levels of trace organics would not be expected in coal bottom ash.

Coal bottom ash would not be expected to leach significant concentrations of trace metals given the extremely low total trace metal concentrations typically present in the coal bottom ash.

3.2.3 Potential Highway Uses and Processing Requirements

Bottom ash has been used occasionally as an aggregate in hot mix asphalt, but usually only when blended with conventional aggregates. Bottom ash, produced in dry bottom boilers, is usually sufficiently well-graded that it does not need to be blended with other fine aggregates to meet gradation requirements. However, bottom ash particles are less durable than conventional aggregates. Consequently, bottom ash is better suited for use in base course and shoulder mixtures, or in cold mix applications, as opposed to wearing surface mixtures. Most of the previous use of bottom ash has been in cold mix projects on low volume secondary roadways.

Coal bottom ash has been used as a granular base material for roads, streets, and parking areas on state, local, and private highway projects. In general, the performances of pavements using bottom ash as a granular base have reportedly performed in a satisfactory manner.

Bottom ash can be used as a fine aggregate fraction, or in some cases, as the entire aggregate in either Portland cement or pozzolan-stabilized base and subbase mixtures. Sometimes bottom ash is blended with coal boiler slag, which can comprise the entire aggregate portion of the stabilized base mix. Bottom ash has been used as aggregate sources in stabilized base or subbase applications since as far back as 40 years ago. Most of these installations have not been well documented, but their service record is believed to have been from fair to very good.

Bottom ash has been used as structural fill materials for the construction of highway embankments and/or the backfilling of abutments, retaining walls, or trenches. Bottom ash also has been used as an aggregate material in flowable fill mixtures.

3.2.3.1 Asphalt Concrete Aggregate

Bottom ash has been used as fine aggregate substitute in hot mix asphalt wearing surfaces and base courses, and emulsified asphalt cold mix wearing surfaces and base courses. The most extensive use of bottom ash in bituminous paving has been in West Virginia during the 1970's and 1980's, where bottom ash was used in cold mix paving applications on numerous secondary roads where traffic volumes are lower and durability concerns are reduced. In some cases, the bottom ash was also blended

with boiler slag. Similar applications have also been made in eastern Ohio and eastern Kentucky. Because of the "popcorn," clinkerlike low durability nature of some bottom ash particles, bottom ash has been used more frequently in base courses than in wearing surfaces. There are no known uses of bottom ash in asphalt surface treatment or seal coat applications.

Screening of oversized particles and blending with other aggregates will typically be required to use bottom ash in paving applications. Pyrites that may be present in the bottom ash should also be removed (with electromagnets) prior to use. Pyrites (iron sulfide) are volumetrically unstable, expansive, and produce a reddish stain when exposed to water over an extended time period.

Bottom ash is handled, stored, mixed, compacted, and placed using the same methods and equipment that are normally used for conventional aggregates. Asphalt mixes containing coal bottom ash can be designed using conventional laboratory techniques. Blending with conventional aggregates will improve the durability of the paving mix. Because of comparatively high optimum asphalt contents of mixtures using bottom ash (due to high bottom ash absorption values), combining bottom ash with conventional aggregates is also recommended. Bottom ash mixes are also likely to have relatively high air void contents. The high air voids are attributable to the rough surface texture of bottom ash particles.

Lay down characteristics of dry bottom ash cold mixes have been found to be excellent, using either a spreader box or a conventional paving machine. Lifts of up to 200 mm (8 in) loose have been attempted in a spreader box with good results. Lifts greater than 200 mm (8 in) in loose thickness may be difficult to compact.

3.2.3.2 Granular Base

Bottom ash has occasionally been used as unbound aggregate or granular base material for pavement construction. When using bottom ash as an unbound or granular base/subbase material, the use of the American Association of State Highway and Transportation Officials (AASHTO) structural equivalency design method is recommended as a granular base design procedure for either flexible or rigid pavements, whichever is applicable. Bottom ashes, used in this application, are considered to be fine aggregates. To meet required specifications, the bottom ash may need to be blended with other natural aggregates prior to its use as a base or subbase material. Screening or grinding may also be necessary prior to use, particularly for the bottom ash, where large particle sizes, typically greater than 19 mm (3/4 in), are present in the ash.

Bottom ash may require stockpiling for a short period of time (at least one or two days) to allow excess water to drain. The ash should not be allowed to become too dry before use. If the ash becomes dusty while in a stockpile, or if dust is generated when the ash is being handled or loaded, it has become too dry and should be wetted enough to suppress further dusting before being used. Deleterious materials, such as soluble sulfates or coal pyrites, should be removed from the bottom ash, boiler slag, or pond ash before attempting to use these materials in a base course or subbase application. Pyrites can be removed from the coal before it is burned using sink-float techniques, or directly from bottom ash using magnetic separation.

Bottom ash can lose its stability when it dries out, making it necessary to keep the material wet (or "flushed") so that construction equipment can operate satisfactorily on its surface. The addition of up to 30 percent fines in the form of coal fly ash may remedy the loss of stability upon drying. Compaction of bottom ash can is accomplished by static steel-wheel or pneumatic rollers, as well as vibratory compaction equipment. Once a bottom ash granular base layer in particular has been properly compacted, it must be protected. A prime coat of asphalt emulsion can be applied to the top surface of the base material to prevent rapid moisture evaporation, stabilize the surface, and provide a bond between the base layer and an asphalt or Portland cement concrete wearing surface. An asphalt binder and/or wearing surface or a concrete pavement should be installed within a reasonable time after sealing the granular base layer in order to minimize traffic on this layer.

3.2.3.3 Stabilized Base

Bottom ash is handled, stored, mixed, placed, and compacted using the same methods and equipment that are normally used for conventional aggregates. The blending or mixing of bottom ash in stabilized base mixtures can be done either in a mixing plant or in-place. Plant mixing is recommended because it provides greater control over the quantities of materials batched and also results in the production of a more uniform mixture.

For cement-stabilized bottom ash mixtures, the primary mix design consideration is a determination of the percentage of Portland cement to be added to the mixture. Trial mixtures using several increasing percentages of cement will be necessary. Usually between 5 and 12 percent Portland cement will be needed to properly stabilize bottom ash for use as a roller-compacted base course. The results of ASTM C593 compressive strength and durability testing should be the basis for selection of final mix proportions.

Stabilized base materials should not be placed in layers that are less than 100 mm (4 in) nor greater than 200 to 225 mm (8 to 9 in) in compacted thickness. These materials should be spread in loose layers that are approximately 50 mm (2 in) greater in thickness prior to compaction than the desired compacted thickness. The top surface of an underlying layer should be scarified prior to placing the next layer. For granular or coarse graded mixtures, steel wheeled vibratory rollers are most frequently used for compaction. For more fine-grained mixtures, a vibratory sheepsfoot roller, followed by a pneumatic roller, is often employed.

To develop the design strength of a stabilized base mixture, the material must be well compacted and must be as close as possible to its optimum moisture content when placed. Plant-mixed materials should be delivered to the job site as soon as possible after mixing and should be compacted within a reasonable time after placement.

After placement and compaction, the stabilized base material must be properly cured to protect against drying and to assist in the development of in-place strength. An asphalt emulsion seal coat should be applied to the top surface of the stabilized base or subbase material within 24 hours or less after placement. The same practice is applicable if a Portland cement concrete pavement is to be constructed above the stabilized base or subbase material.

3.2.3.4 Embankment or Backfill Material

Bottom ash and ponded ash have been used as structural fill materials for the construction of highway embankments and/or the backfilling of abutments, retaining walls, or trenches. These materials may also be used as pipe bedding in lieu of sand or pea gravel. To be suitable for these applications, the bottom ash or ponded ash must be at or reasonably close to its optimum moisture content, free of pyrites and/or "popcorn" like particles, and must be non-corrosive. Reclaimed ponded ash must be stockpiled and adequately dewatered prior to use. Bottom ash may require screening or grinding to remove or reduce oversize materials (greater than 19 mm (3/4 in) in size.

3.2.3.5 Flowable Fill Aggregate

Bottom ash has been used as an aggregate material in flowable fill mixes. Ponded ash also has the potential for being reclaimed and used in flowable fill. Since most flowable fill mixes involve the development of comparatively low compressive strength (in order to be able to be excavated at a later time, if necessary), no advance processing of bottom ash or ponded ash is needed. Neither bottom ash nor ponded ash needs to be at any particular moisture content to be used in flowable fill mixes

because the amount of water in the mix can be adjusted in order to provide the desired flowability.

4.0 Preliminary Groundwork and Site Visits

Kentucky Transportation Center researchers conducted a very limited amount of field reconnaissance to document the locations and condition of the byproduct material sources. Specifically, two electrical power producing plants were visited; the Mill Creek facility of Louisville Gas and Electric (an E.ON U.S. plant) in Jefferson County located on the Ohio River, and the American Electric Power Big Sandy Plant located in Lawrence County on the Big Sandy River. On-site interviews were conducted with materials managers to discuss their byproduct materials, any historical process changes, historic handling of the materials, past and current storage and management practices, and to obtain past chemical and physical analytical data. The sources designated by the materials producers were located and photographed for future reference. Kentucky Transportation Center personnel also contacted the University of Kentucky's Center for Applied Energy Research (CAER) to gather historical information derived from surveys conducted by the CAER to document coal ash characteristics.

E.ON U.S is headquartered in Louisville, Kentucky and aggressively markets their ash products. E.ON U.S, or its subsidiaries, operates 13 electric power plants in Kentucky. Since 1998, E.ON U.S. has beneficially reused more than 10 million tons of coal ash for a variety of construction and community projects. As available storage space is becoming more limited, E.ON U.S. has found effective ways to recycle environmentally safe coal ash to benefit community projects, reduce storage costs, and save scarce landfill space. Coal ash from E.ON U.S. power plants has been used in concrete mixtures and wallboard, roofing shingle granules and as fill for state highway projects and trenches associated with drainage and sewer work by Louisville's Metropolitan Sewer District. E.ON U.S. has explored and evaluated various ways to beneficially use coal ash from their facilities. The following are some of the past and present beneficial reuse projects involving E.ON U.S. and its subsidiaries:

LG&E and Charah Inc., a Louisville-based ash management company, announced in June, 2006 a coal ash recycling project that will result in additional community green space. LG&E and Charah will ultimately provide approximately 900,000 tons of coal ash from the utility's Mill Creek plant to back-fill a former sand mine site as part of a beneficial reuse project. Once filled with coal ash, the parcel of land will be covered with a layer of soil, seeded, and donated as a community green space. The project will take approximately 30 months to complete. Kentucky Utility's Tyrone Power Station reached an agreement to improve Woodford County Park by using 45,000 tons of coal ash to develop a parcel of land to create new youth baseball fields for future generations of children. More than 90,000 tons of coal ash from Tyrone also was recycled to develop land for commercial businesses in Lawrenceburg, Ky. Louisville's Metropolitan Sewer District (MSD) completed a project in southwest Jefferson County to connect that part of the county to its sewer system. Large volumes of sand were required to backfill trenches after sewer lines had been laid. LG&E's Mill Creek Power Station, in conjunction with Charah, Inc. provided washed and sized coal bottom ash as replacement material for sand. More than 400,000 tons of coal bottom ash was used in this project. A warehouse in Jefferson County sits

on 120,000 tons of reclaimed coal ash from LG&E's Mill Creek Power Station. Using coal ash was less expensive for the developer and preserved natural resources. The coal ash was compacted in layers to supply a solid base for the warehouse to be built upon.

Large volumes of fill material were required to construct an embankment, and access to a new bridge over Dixie Highway in Jefferson County. LG&E, in conjunction with Faulkner Construction, supplied more than 620,000 tons of coal ash from the Mill Creek Power Station. The coal ash was used as a foundation material to allow the road to be constructed.

Coal fly ash is also used as a raw material in cement production. LG&E's Mill Creek Power Station annually supplies over 180,000 tons of fly ash to Cemex Inc., a cement plant located in nearby Valley Station. This coal ash replaces the natural clay that historically was mined from pits on Cemex's property. Coal fly ash is also used as partial cement replacement in concrete. Fly ash is less expensive than cement and has been demonstrated to produce more durable concrete. LG&E's Mill Creek and Trimble County Power Stations, in conjunction with Mineral Resource Technologies, market this fly ash to local concrete producers. This ash is also sent by railroad to markets as far away as Florida and Arizona. Synthetic gypsum is a byproduct of the scrubber process, which removes sulfur from power plant flue gases at the Mill Creek Plant. This material is used to replace natural rock gypsum which must be mined to make wallboard. E.ON U.S. recycles more than 1.2 million tons of synthetic gypsum annually. This material is shipped by truck to local producers and by barge as far away as Alabama.

American Electric Power (AEP), headquartered in Columbus, Ohio also has an aggressive ash marketing program. AEP's Big Sandy Plant produces more than 225,000 tons of ash per year, 80 percent of which is bottom ash. A one-mile experimental bituminous overlay was placed on State Route 3 in Lawrence County, Kentucky in the late 1980's. The bituminous surface mixture consisted of 40 percent bottom ash aggregate, 40 percent size No. 8 limestone aggregate, and 20 percent natural sand. Approximately 540 tons of the experimental bituminous surface material was used. There were no observed performance deficiencies of the experimental surface when compared to the conventional control surface. Skid numbers obtained for the experimental surface were found to be equivalent to the adjacent conventional section even though the average daily traffic was nearly three times greater for the experimental section. This project demonstrated that bottom ash aggregate can be successfully substituted for a portion of the coarse aggregate and performs well in a bituminous surface mixture. Bottom ash represents a large potential source of high-friction, nonpolishing aggregate for use as an aggregate substitute in bituminous surface mixtures.

Bottom ash from AEP's Amos Power Plant, located near Charleston, West Virginia, was used as a backfill material for the construction of the I-64 / U. S. Route # 35 Interchange near Hurricane, West Virginia. It was estimated that approximately 170,000 cubic yards of bottom ash were used during this project. The reason bottom ash was chosen as the backfill material for the project was due to its superior physical and chemical characteristics as compared to natural materials. The project called for a backfill material with a neutral pH, appropriate electro-negativity, and to be light weight due to the engineering characteristics of the soils in the area. The plant's bottom ash met all the engineering requirements and was the material of choice due to its low cost. Approximately 14,000 tons of fly ash from AEP's Rockport Power Plant, located

near Rockport, Indiana, was used as a pozzolan in the concrete poured for the reconstruction of I-70 in Clark County, Indiana. LaFarge North America, the plant's fly ash marketer, provided the technical and logistical support required for the project. Fly ash and bottom ash from AEP's Oklaunion Power Plant, located near Vernon, Texas, has been used successfully as a road base material. Boral Materials Technologies, the plant's coal combustion product marketer, is using the plant's fly ash and bottom ash for their Boral RoadMix Base™ product. This combination of bottom ash and pelletized high calcium fly ash is produced in a patented process using a Boral MACS® machine. RoadMix Base provides high durability as a semi-rigid, non-plastic road base material. Its stability also makes RoadMix Base very effective in certain fills and beneath construction slabs.

It is evident, that in order to increase the use of byproduct materials as construction materials within the Commonwealth of Kentucky, information for those materials must be available to the designers of highway construction and maintenance projects. The most efficient way to accomplish increased utilization of byproduct materials is to develop a secure information system whereby material producers and KyTC personnel could access and manage information relative to these materials.

5.0 Developing the KyTC Byproduct Information System

The KyTC Byproduct Information System (KyTCBIS) was designed to be a centralized warehouse of information relative to byproduct materials produced in Kentucky. The viability of the KyTCBIS will depend upon the producers of byproduct materials that have a genuine interest in, and commitment to, utilizing their waste materials for something other than filling a landfill or lagoon. Material producers will be required to upload collected information about their byproduct materials to the KyTCBIS. Likewise, highway designers also will be required to upload data collected relative to laboratory and field tests, and performance history of applications wherein byproduct materials are used. In order to promote the increased use of these materials, producers and highway designers must work together to share information about the feasibility of using the materials in highway construction and maintenance projects.

Researchers evaluated the static database developed by the University of New Hampshire under NCHRP project 4-21 and recognized the potential to use something similar, yet vastly different, to fulfill the desire to have a comprehensive information system containing data regarding sources of byproduct materials within Kentucky and their environmental and engineering characteristics. Therefore, the KyTCBIS was designed to be dynamic and to easily facilitate uploading of data that are normally obtained by byproduct material producers for environmental assessments, quality control, and determining engineering properties. These data typically include evaluations of environmental and engineering properties that are routinely conducted on an annual basis.

The requirements for the KyTCBIS were specified such that material information could be presented in a logical format to the users of the system. The KyTCBIS was designed to be hosted on a secure client-server with users having differing levels of access and user permissions as defined by a system database administrator (SyDBA) from KyTC. The SyDBA would control

all access to the KyTCBIS by granting appropriate user privileges based upon the requirements of the user. The different user levels include viewers, site materials managers and data entry operators. KyTCBIS viewers would have permissions granted by the SyDBA to only view the available information. A viewer could not upload or manipulate any of the data contained in the KyTCBIS. Site materials managers would be approved by the SyDBA and would be granted permissions to upload and manipulate data only for the sites, or plants for which they are responsible. A data entry operator would be someone designated by the site materials manager, and approved by the SyDBA, to upload and manage data only for the site(s) as designated by the site materials manager. Information for the byproduct materials would be uploaded and maintained by both the material producers and the material users. Producers of byproduct materials would be responsible for uploading results of routinely performed testing relative to determining the environmental or engineering properties of a byproduct material. Users of the byproduct materials (KyTC primarily) would be responsible for uploading results of any tests performed for the purpose of determining engineering properties for design of an application using a byproduct material, field validation of the material's environmental and engineering properties, or performance measures made after placement of the material.

The various graphical user interfaces and technical documentation for the KyTCBIS is included in Appendix A.

6.0 Conclusions and Recommendations

The purpose of this study was to develop and design a dynamic byproduct information system that would contain specific chemical, physical, and mechanical properties of Kentucky's abundant byproduct material sources. The result of this research effort is the Kentucky Transportation Cabinet Byproduct Information System, or KyTCBIS. Millions of tons of fly ash and bottom ash are produced each year from coal-fired power plants in Kentucky. These materials have proven engineering properties that make them especially suitable for constructing highway embankments and other geotechnical structures. Use of these materials in certain situations can provide large cost savings, especially in "borrow" fill situations

Due to the short time frame available for actual development of the KyTCBIS, there remains much to be done to make the KyTCBIS a complete, dynamic information system for the Kentucky Transportation Cabinet, producers of byproduct materials, and construction contractors. Items that remain to be addressed include:
- Adding a data file upload feature,
- Adding a Picture upload feature to all elements,
- Implement the remaining Google Maps features.
- Allow for Comma Separated Value and Excel exports,
- Create a comprehensive web based user manual,
- Add screen casts (video) to explain common tasks, and
- Add more polish to the user interface.

There were items that should have been addressed, but were not, including:

- Not having a user type that can edit everything but not edit user privileges (Transportation Cabinet personnel), not requiring verification for viewers. (It is currently an open-to-the-public design).

Things that researchers could have done to make the project better:
- Define the actual time frame for development of the KyTCBIS,
- Define the exact user base of the application,
- Define the required feature list as well as the optional feature list,
- Define the scope of the data that are to be contained in the KyTCBIS,
- Better determine the interest and concerns of material producers, and
- Better determine the interest and concerns of contractors.

Each ash producer within Kentucky, and even in the contiguous states, should be contacted to develop their interest in using the KyTCBIS to their advantage. Although only two plants were visited by researchers during the study (E.ON U.S and its subsidiaries control 13 of the facilities 21 coal-fired power plants in Kentucky), this effort will involve getting each plant manager to upload their chemical and physical property data pertaining to fly ash and bottom ash to the KyTCBIS. By populating KyTCBIS, this information will be available statewide to the Kentucky Transportation Cabinet. Techniques were built into the KyTCBIS that will make it easy for plant managers and others to upload and manage their information. Screen cast, or videos, need to be developed that would completely illustrate how to use all functions in the KyTCBIS. This video stream should be added to the system for self help. Informal meetings with plant mangers will be needed to introduce them to the KyTCBIS and obtain feedback on ways to improve the information system. Graphical functions should be added to the information system so that "on-line" graphs could be created. Graphical functions are needed so that certain chemical properties, such as a given type and amount of a selected heavy metal, could be graphed as a function of time and any changes in these properties (over time) could be readily discernable to product users.

Further, efforts should be reinitiated to work with the University of Kentucky Center for Applied Energy Research (CAER) to access vital chemical data routinely collected by the CAER. The CAER collects samples from each coal-fired power plant every five years and performs chemical tests on those collected samples. Those data would be significant for populating the KyTCBIS and would provide a central information source of chemical data for fly ash and bottom ash produced in Kentucky. Such information would be of vital interest to the Cabinet in judging the engineering uses of those materials. Specific site and performance data where fly ash and bottom ash have been used at highway sites, as well as building sites, should be collected and added to the KyTCBIS. This effort would provide the information that would ultimately demonstrate that fly ash and bottom ash have been used at many engineering sites in Kentucky, some successfully and some not successfully. Collecting and compiling case studies of sites where these materials have been used would aid in supporting the use of the byproducts at new construction sites when economical.

APPENDIX A

**Developing the Kentucky Transportation Cabinet
Byproduct Information System**

A.1.0 The Kentucky Transportation Cabinet Byproduct Information System

The Kentucky Transportation Cabinet's Byproduct Information System (KyTCBIS) was developed so interested byproduct material producers could provide information about their products and KyTC engineers would have an information source available to guide their decisions with regard to byproduct or recycled materials in highway construction and maintenance applications. This information would include both engineering and environmental properties so that the materials could be properly considered for economical use in new highway construction and maintenance projects throughout Kentucky. It is the responsibility of the material producer to establish an economic use zone for their materials. Engineers with KyTC will access the information provided by the byproduct material producers and determine, through value engineering, whether or not the product could be used safely and economically for a given project, based on the material's chemical, physical and mechanical properties and proximity of the project to the material source. Of course, prior to using any byproduct material in a highway construction or maintenance activity, the KyTC would perform a battery of tests to validate the information provided by a producer relative to a particular source. Further, the results from these tests would be added as additional documentation to the KyTCBIS. Additionally, as the byproduct materials are used, the results of any tests performed during placement and subsequent performance measures would be added to the byproduct material's information profile.

It is anticipated that there will be two (2) primary users of the KyTCBIS; byproduct material producers and KyTC engineers. There also will be site viewers but the site viewers will have permissions to view only the available information, not to add or edit the data. The primary users will be responsible for maintaining and updating the KyTCBIS with data determined from measuring the environmental, engineering and performance properties of a byproduct material while site viewers will only be allowed to "view" the information about a particular material.

The KyTCBIS was developed to be modular so that all recyclable materials that have demonstrated, or could possess the potential for successful use in highway construction and maintenance projects could be included; things such as scrap tires, asphalt shingles, glass and others.

Various graphical user interfaces of the KyTCBIS are illustrated and described herein.

A.1.1 Log On

The log on screen is illustrated in Figure 2 and is the first screen in the KyTCBIS. The user may either sign in using a User ID and Password or Register as new user.

A.1.2 Information Requested From User

When the "Register" tab is clicked, as shown in Figure 2, the user is requested to supply certain types of information, as shown in Figure 3. If an asterisk appears by a field, then the information is required for registration as a user. Information requested includes name, User ID (created by the user), password (created by the user), email, contact phone number, street address, city, state, zip code, country, organization (not required), desired
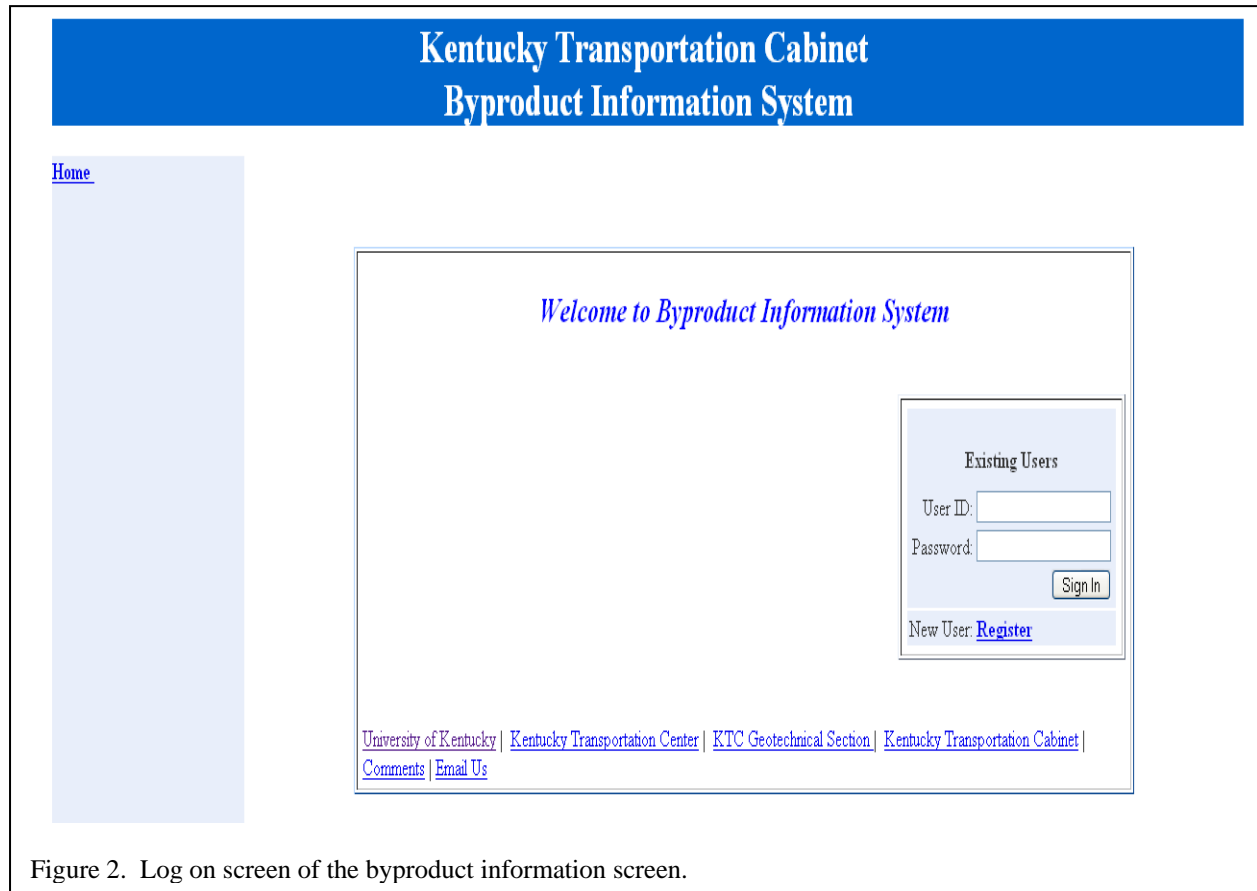
Figure 2. Log on screen of the byproduct information screen.

user designation, and description. Information supplied by the user is confidential and maintained in the KyTCBIS. For the information to be registered, all required information must be supplied to become a user of the KyTCBIS.

A.1.3 Welcome Screen

After the user logs into the KyTCBIS, a "Welcome" screen appears, as shown in Figure 4. On the left side of this screen a navigation bar appears which allows the user to get information quickly. This screen always appears while the user is logged in. The middle of the screen is the viewing area. On the top right corner is the "User Administration" links and Logout. This link provides the means for the system administrator to change user-related information such as passwords.

A.1.4 Drop down menu of the Site Administrator

Figure 5 shows the same screen as in Figure 4 but the "Site Administrator" dropdown menu is shown. This menu lists sites and materials that have been previously created by the site administrator. In this pull down menu, the site administrator can only edit those sites that he/she has previously registered and logged onto.

Figure 3.   Types of information requested from a new user.
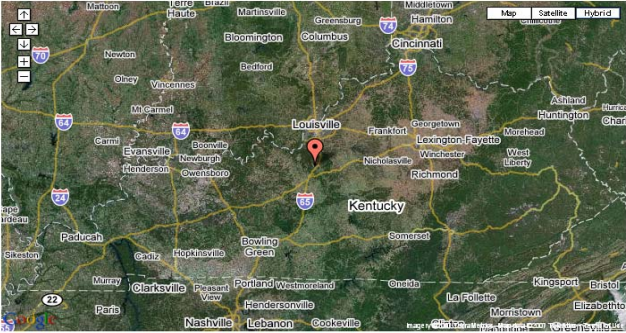
Figure 4. Welcome screen and various links.

Figure 5. Drop down menu of the site administrator.

A.1.5 Editing Material Attributes

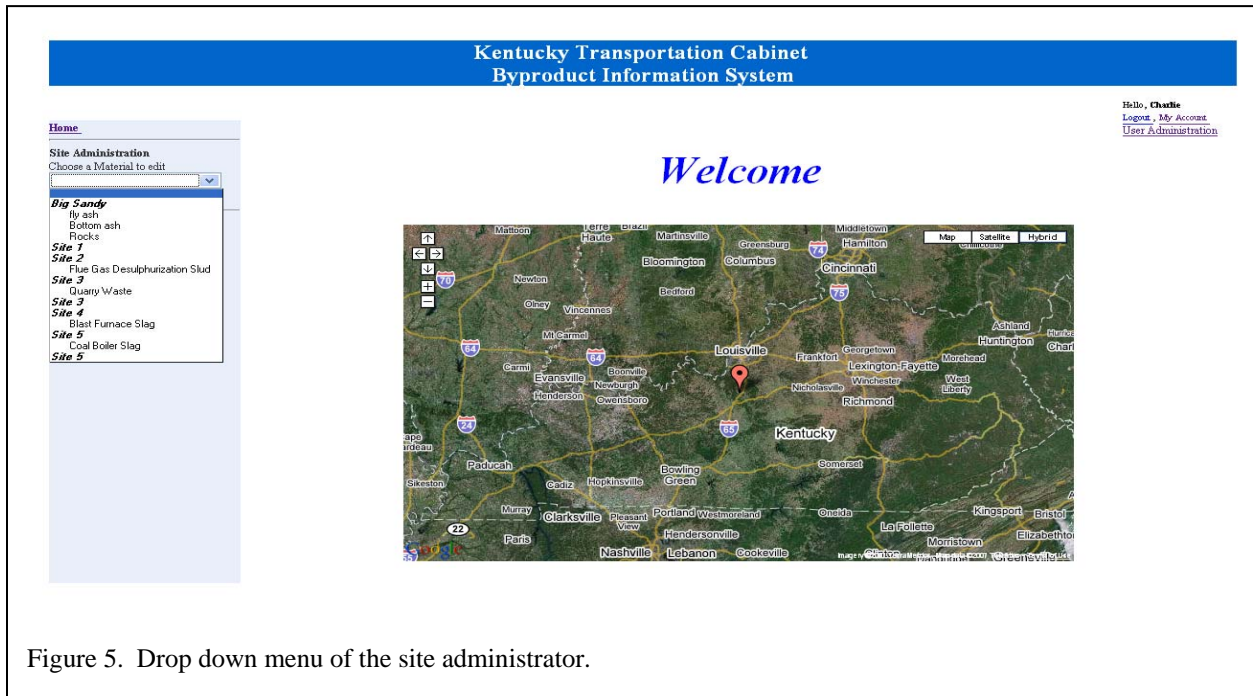As shown in Figure 6, the user may edit a selected material from the dropdown menu in Figure 5. In this case, the user wishes to edit "fly ash." Information concerning the material, such as "Material Description," "Potential Uses," or "Production Process" may be edited at this screen. The user may edit the engineering properties, environmental properties, or the application. A new property may be added. Laboratory and field tests performed on the material may be edited on this screen.
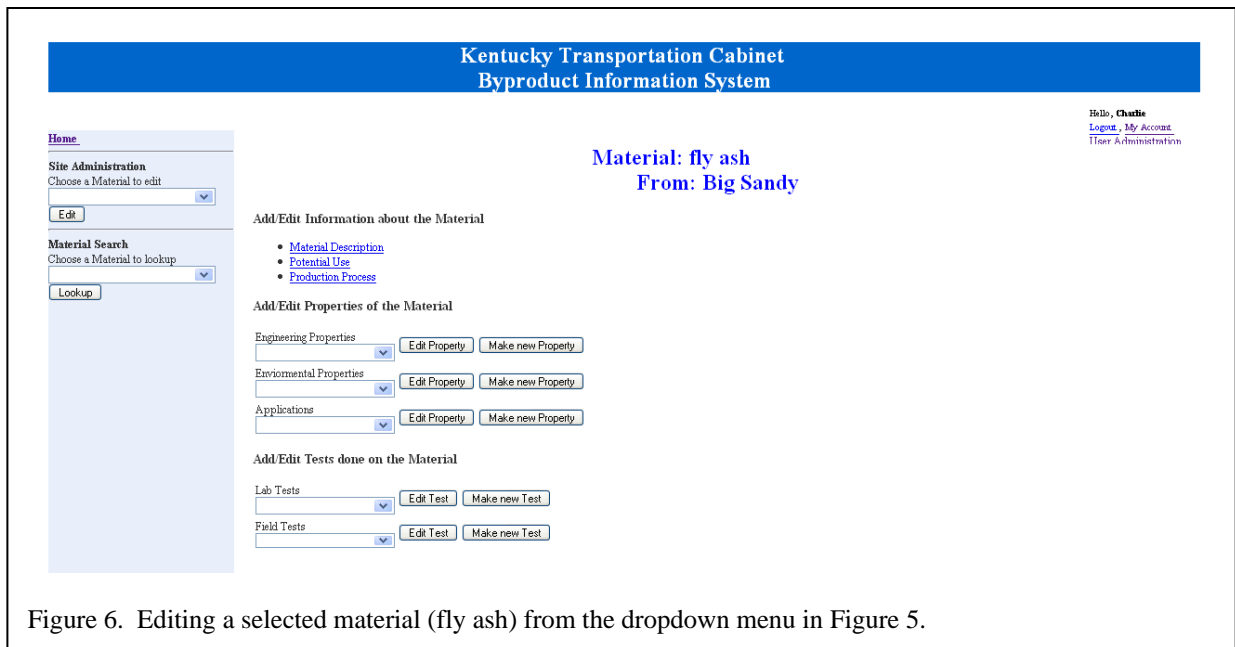
Figure 6. Editing a selected material (fly ash) from the dropdown menu in Figure 5.

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A.1.6   Changing an Engineering Property of a Selected Material

If a user chooses to change an engineering property of a selected material, then the screen in Figure 7 may be used to edit, in real time, the Property Name, Property Type and Description through the web browser.
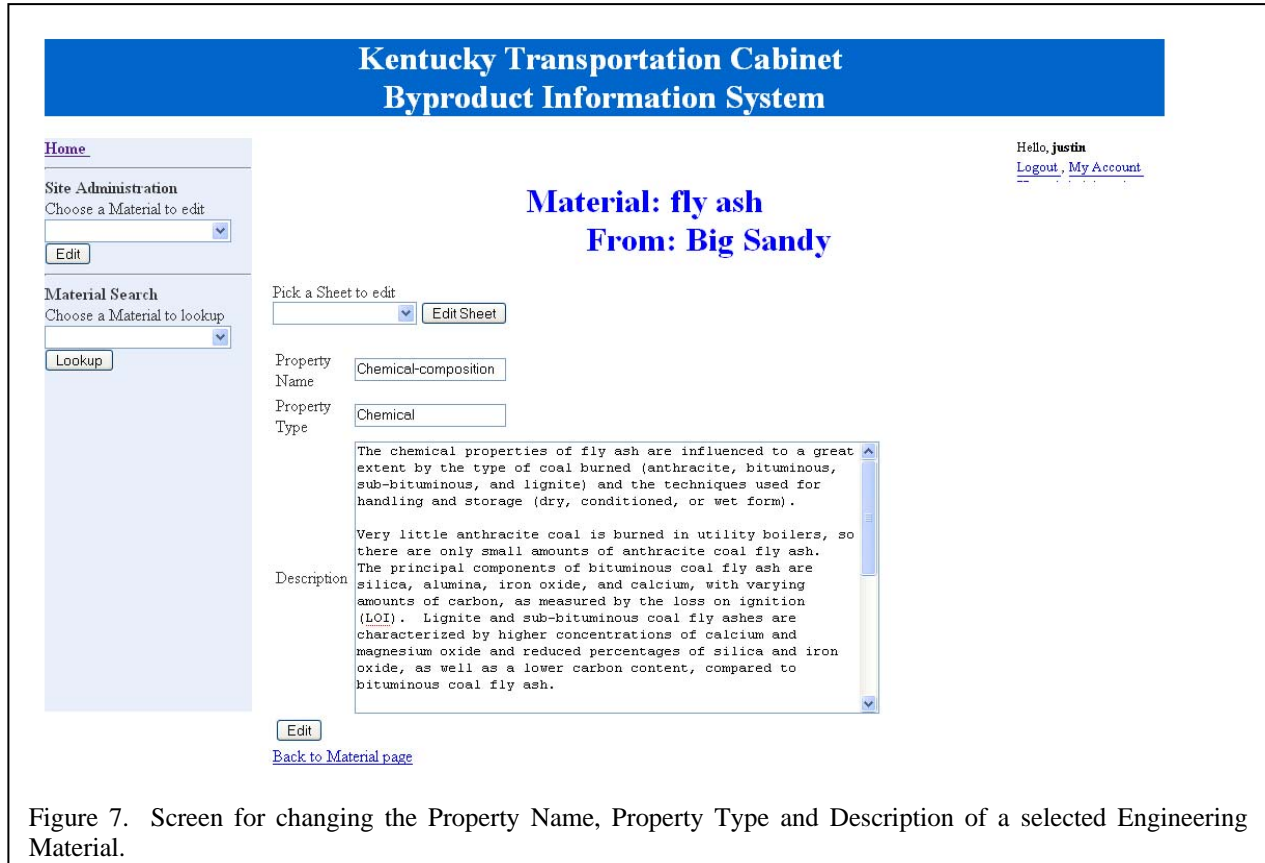

Figure 7.   Screen for changing the Property Name, Property Type and Description of a selected Engineering Material.

A.1.7 Making a New Sheet and Uploading Data

The screen for making a new sheet is shown in Figure 8. The name for the new sheet is first selected and entered. The browse button is used to search the user's local disk for a CSV (Comma Separated Value) File. CSV files can be exported from a spreadsheet application (for example, Excel or Lotus). Once this task is performed, after clicking on the "Upload" button, the CSV file will be transformed into a sheet that is associated with the given property.

A.1.8 Material Search

A material search may be performed by clicking the dropdown menu under "lookup" (under "Material Search,") as shown in the "Navigation Bar' in the left-hand portion of the screen in Figure 8.   After selecting a material, the screen shown in Figure 9 appears. The user sees a description of the selected material and a photograph. A routine for uploading a photographs of a selected material is included in the system.

Figure 8. Making a new sheet.

Figure 9. Material Description

A.1.9 Material Description

To obtain a description for some of the uses of a material, the "Uses" link in the left-hand portion of Figure 9 is clicked. When this action is performed, the screen in Figure 10 appears. As shown in this example, the many uses of fly ash are described.
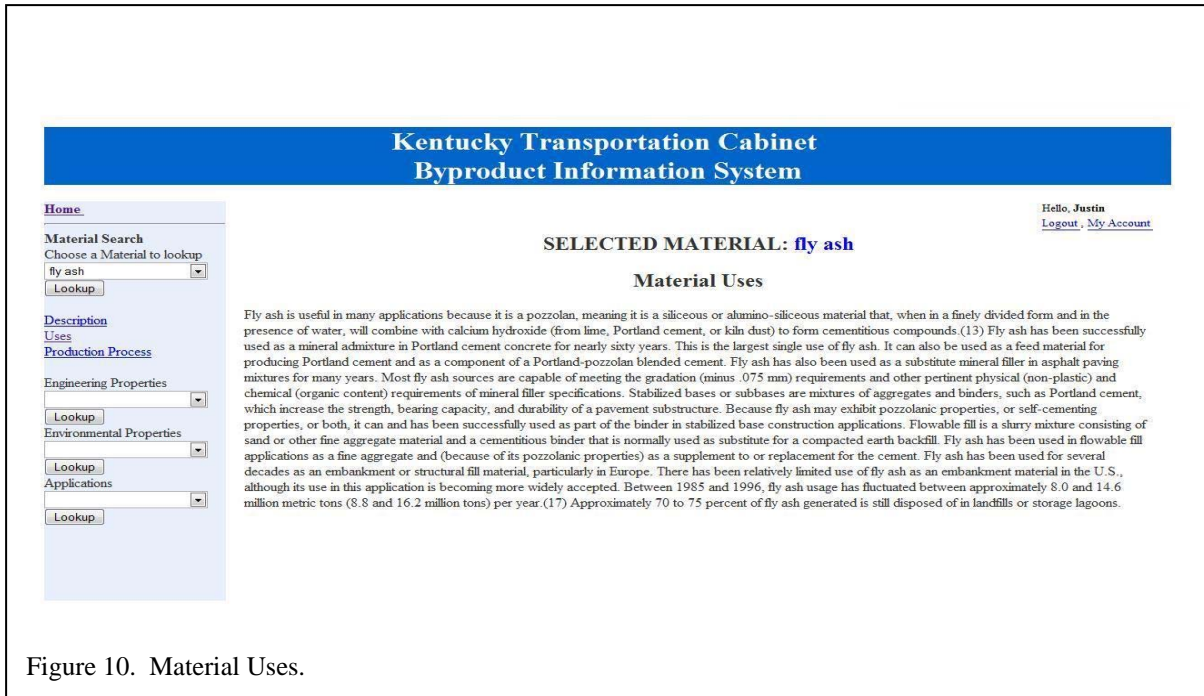
Figure 10. Material Uses.

A.1.10 Production Process

A screen (not shown) is also accessible to include a description of the "Production Process" for a selected material.

A.1.11 Material Uses

As shown the lower, left-hand corner of Figure 10, data pertaining to the engineering properties, environmental properties, and applications of a selected material may be stored and retrieved. For example, if a material in the drop down menu under "Environmental Properties" is clicked, then the screen shown in Figure 11 appears. There is a Description shown as well as an area to display the associated sheets. If multiple sheets need to be viewed, then user may view the appropriate sheet by clicking on the tab containing the date (in this case, "5/5/05"). Multiple tabs containing multiple sheets of data may be created when data are uploaded. See Section A.1.7.

A.1.12 Pending Requests

If a user has initially registered as an "Administrator" or "Site Material Manager" (see Figures 2 and 3) and clicks on the "User Administration" link, which appears at the top
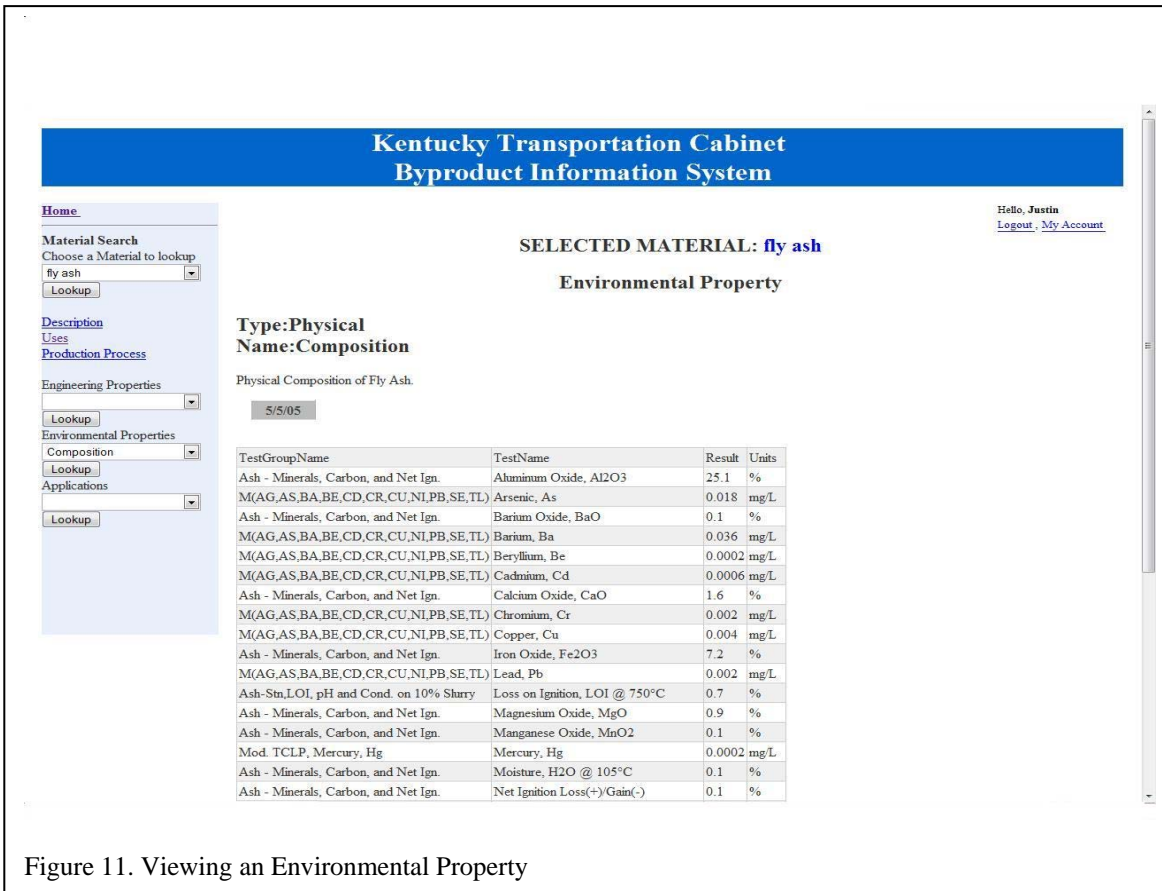
Figure 11. Viewing an Environmental Property

left-hand portion of each screen, then the screen displayed in Figure 12 appears. The screen does not appear if; the user has registered as a "Viewer" or "Data Entry Operator." From this screen the Administrator or Site Material Manager may deny or approve pending requests.

A.1.13 Viewing a Pending Request

When the "Administrator" or "Site Material Manager" chooses to view a pending request, the screen in Figure 13 appears. This is useful to determine if a request is valid before approving or denying it.

A.1.14. Viewing and Editing Account

When the link, "My Account" in the upper right-hand corner of each screen is clicked the screen in Figure 14 appears. All users may go to this screen but each user can only change their current users' data. A user can change their password or any of their contact information using this screen.

A.2.0 Technical Documentation of the KyTCBIS

The purpose of the Kentucky Transportation Cabinet Byproduct Information System is to develop a
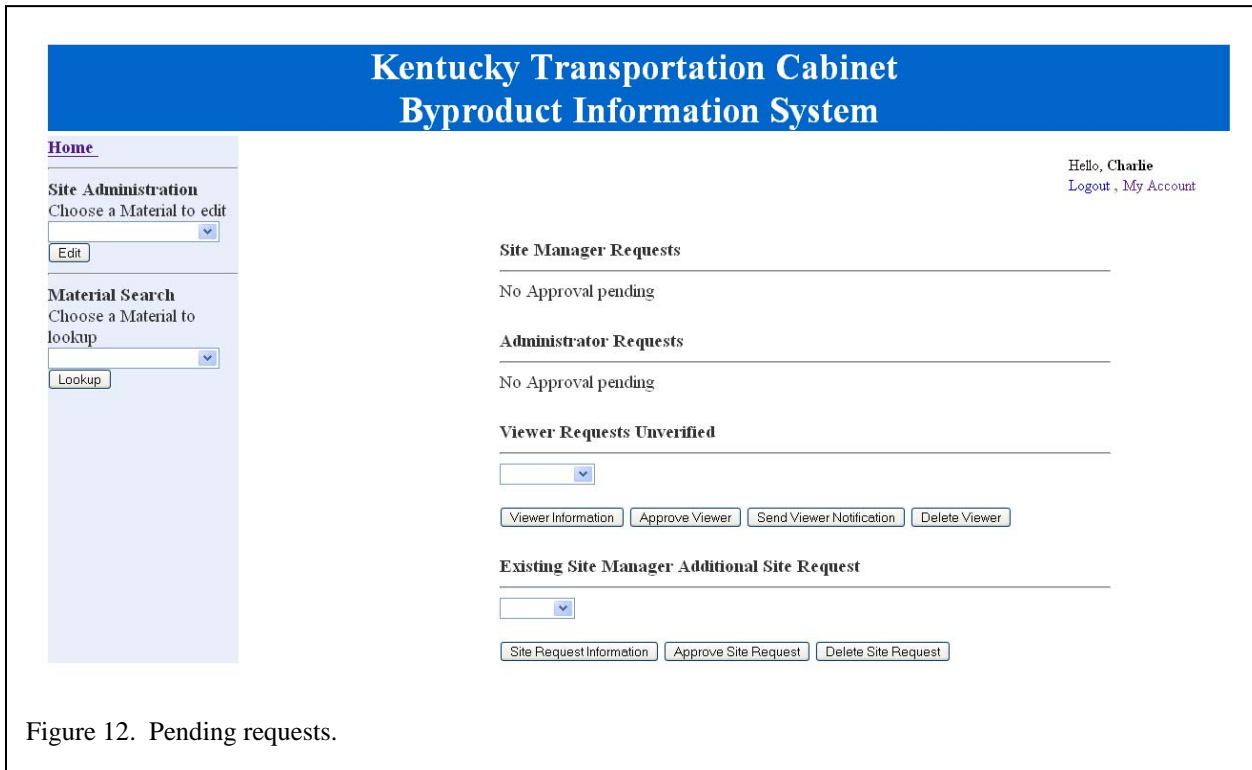
Figure 12. Pending requests.
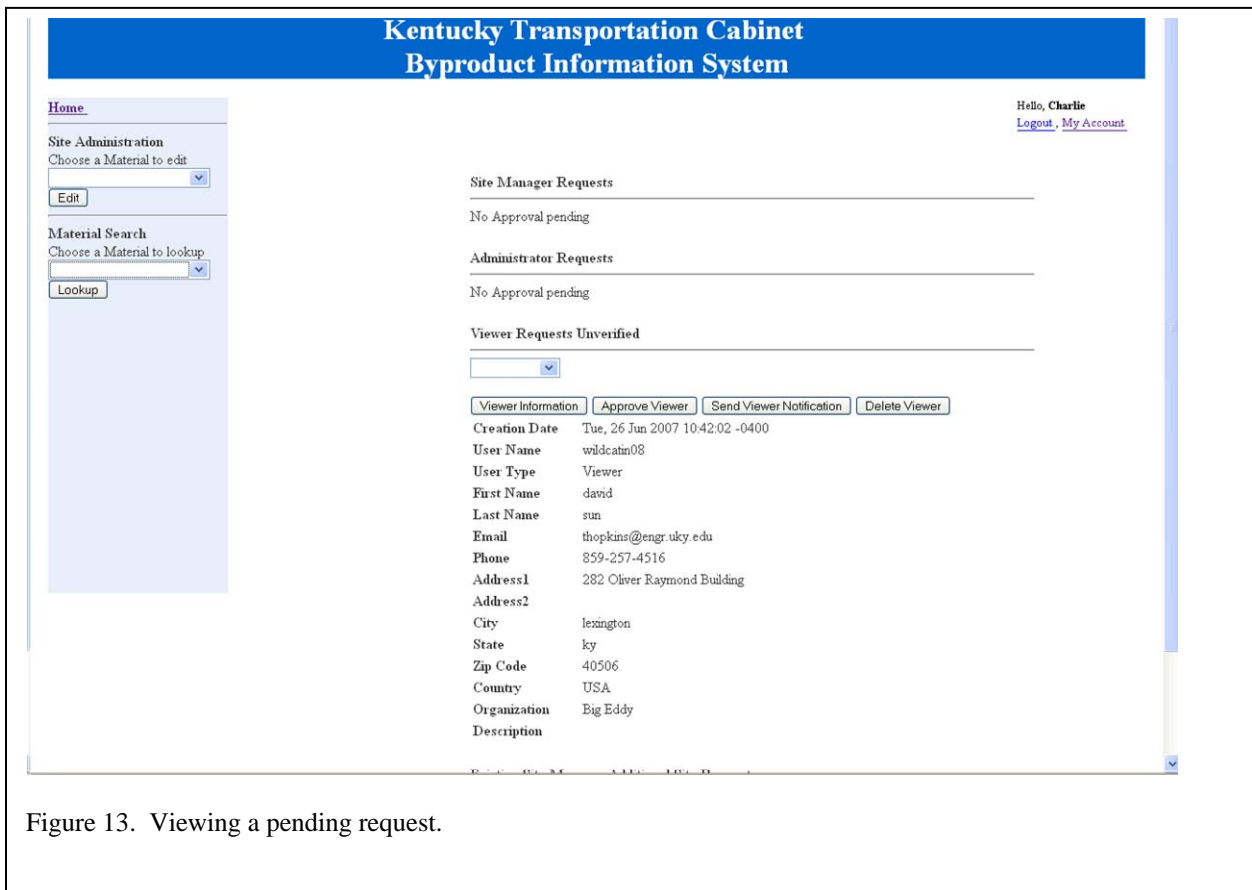
Figure 13. Viewing a pending request.
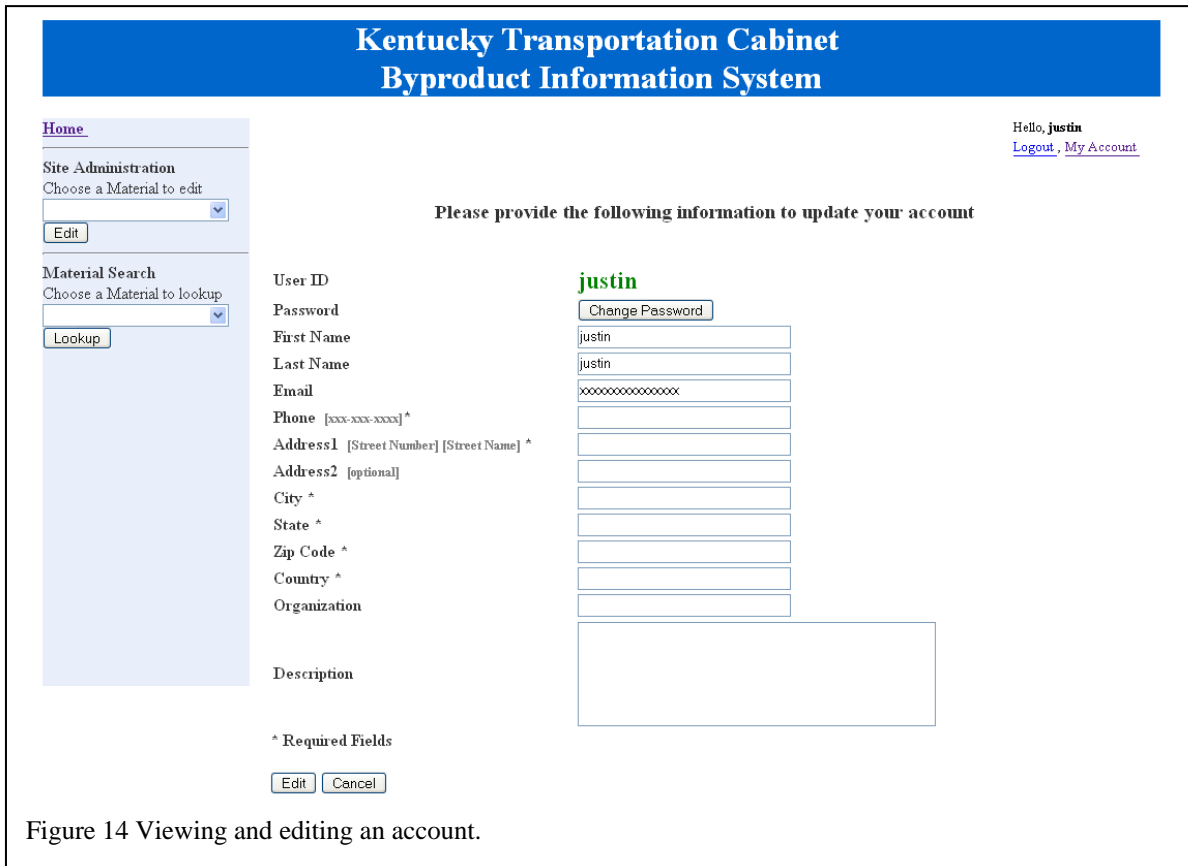
Figure 14 Viewing and editing an account.

framework that allows construction engineers (especially highway construction) to assess the usability of byproducts produced in various plants in Kentucky. The project implements a web application, which shows the end users of the system the various byproducts produced in different plants in Kentucky and their locations along with their environmental and engineering properties, recommended applications for the byproducts and various tests performed to prove these byproducts can be efficiently and effectively reused.

A.2.1 Technologies

Many different technologies were used during development of the KyTCBIS. This section outlines what technologies and applications were used for development as well as the justification for each.

A.2.1.1 Server Technologies

These technologies purely reside on the server that holds the KyTCBIS. These technologies are transparent to the non-developer. Because of this transparency, neither the user nor the Client PC being used is required to know or understand anything about these technologies.

A.2.1.1.1 Web Server: Apache 2

The web server is mainly used to serve the content created and held by the KyTCBIS to the Client PC. The Web Server is also used as the go between for the PHP and Client PC.

Apache 2 was used for the web server for four reasons. First, it is open source and is therefore free to be used and distributed without any restriction. Second, it can be installed on many different operating systems including Windows, Linux, UNIX, Mac OSX, and Solaris. Third, it is the most widely used web server on the market so support is terrific. Fourth, it is very stable and extremely secure due to constant updates and patches.

There are no other known web servers that could be used as alternatives for Apache 2 for use of the KyTCBIS.

The other web servers that were considered were Microsoft Internet Information Services (IIS) and Sun Java System Web Server (JSWS). IIS was not chosen because IIS is not free, IIS can only run on a Windows-based server, and there were concerns about IIS's security. JSWS was not chosen because JSWS is not used that often and is therefore hard to support. JSWS would require Java to be installed on the server, and JSWS is much slower than the alternatives.

A.2.1.1.2 Server Scripting Language: PHP 4

The server scripting language is run through the web server to generate the content that is served to the Client PC. The server scripting language also inserts, edits, and queries the SQL Database to generate the content provided by the KyTCBIS.

PHP 4 was used as the server scripting language for many reasons. First, it is an open source application which allows it to be freely used and distributed. Second, PHP is very C like (a compiled programming language) and simple to read and interpret. Third, PHP is not a variable type strict language allowing for faster development and flexibility. Fourth, PHP does not have to be complied like some other languages allowing the file to be edited on the fly with a simple text editor without restarting the server. Fifth, PHP can be installed on many different operating systems including Windows, Linux, UNIX, Mac OSX and Solaris.

With testing, the KyTCBIS could possibly run on a server that is running PHP 5 but that has not been tested. There are no other tested and known alternatives for PHP 4 for use in the KyTCBIS

The other server scripting language that was considered included ASP. ASP was not chosen because ASP is Windows specific and would limit portability and ASP would require the use of IIS which is not free.

A.2.1.1.3 SQL Database: MySQL 4

The SQL database is run on the server and is queried by the server scripting language. The SQL database holds all of the dynamic data that is used in the system.

The SQL database chosen to run the KyTCBIS was MySQL 4. MySQL was chosen for many different reasons. First, MySQL is open source and is therefore freely used and distributed. Second, MySQL is widely used and supported. Third, it can be installed on many different operating systems including Windows, Linux, UNIX, and Mac OSX.

There are no tested and known replacements for MySQL for running the KyTCBIS database.

Alternatives to MySQL that were considered included; Oracle, Microsoft SQL Server, and PostgreSQL. Oracle and Microsoft SQL Server were not chosen because neither choice was free and they both limit the supported operating systems that can be used. PostgreSQL was not used and MySQL is more popular and considered to be faster.

A.2.1.2 Client Technologies

These technologies are required by the Client PC for the end user to use the KyTCBIS. These technologies do not need to be available to the Hosting Server. Technologies used by the Client PC are uncontrollable by the Hosting Server or by the Hosting Provider.

A.2.1.2.1 Client Language: HTML\XHTML

The client language is the language the Client PC receives from the Hosting Server and is interpreted by the Client Browser.

The client language chosen for the KyTCBIS was HTML\XHTML. XHTML was chosen because it is the only protocol that is fully supported by all the major Client Browsers and because it is highly supported.

The KyTCBIS is run strictly through HTML\XHTML and there is no way to remove this from the KyTCBIS without remaking the entire system.

There were no other client languages considered.

A.2.1.2.2 Client Language Styling: CSS

Client language styling is a technology of keeping the visual detail separate from the client language. This allows for easy editing of how the entire KyTCBIS system looks from just one single edit.

CSS was chosen because it is the only client language styling protocol that works with XHTML

The KyTCBIS is run strictly through HTML\XHTML which requires the CSS and there is no way to remove this from the KyTCBIS without remaking the entire system.

There were no other client languages considered.

A.2.1.2.3 Dynamic Client Language: JavaScript

A dynamic client language is used to provide for more functionality than is available with standard XHTML. A dynamic client language can also be used to offload some work from the Hosting Server to the Client Browser and Client PC.

The dynamic client language chosen for the KyTCBIS is JavaScript. There are many reasons this was chosen. First, JavaScript is the most commonly used of the dynamic client languages. Second, JavaScript is very much like Java so it is very easy to learn. Third, JavaScript integrates well into the existing XHTML/CSS system.

This is integrated into the KyTCBIS and must be used by the client. Currently there is no JavaScript code that is required to use the site so if a Client Browser does not support JavaScript it is okay.

The alternatives for JavaScript that were considered were DHTML and Flash. DHTML was not chosen because it did not support the desired features of the project. Flash was not chosen because it would require proprietary software to develop and it did not have all the desired features.

A.2.1.3 Development Technologies

These technologies were used in development of the KyTCBIS and are not needed for production nor are they required for future development. Justifications will not be given for these technologies as they can be replaced or omitted depending on future development preferences and needs.

A.2.1.3.1 FTP: FileZilla Client and Server

This was used to transfer files between the server and development computers.

A.2.1.3.2 File Editing: Komodo Edit

This was used to edit and create the files used in the KyTCBIS.

A.2.1.3.3 Web Based Database Administration: phpMyAdmin

This was used to manually add, edit, and remove entries in the database through the development site.

A.2 Modules

During development it became obvious that the project needed to be broken up into different logical groups of files so no file or feature would get recreated or overwritten. Module is just the term that was used for these groupings. The modules included in the KyTCBIS are the View Module, User Management Module, and Content Edit Module.

A.2.1 View Module

The Site View module enables any authorized user of the KyTCBIS to view the various byproduct material producers in Kentucky that are registered with KyTCBIS. Upon choosing a particular Site, the view module displays the byproduct materials produced at that Site. Each material may have different properties/applications and results of tests conducted on the material. A viewer can view specific information by choosing a material and clicking the appropriate button option provided to view details or specifications. For example, descriptions of the byproduct material and other specific details of engineering properties/environmental properties and applications can be viewed for any material by just clicking on the appropriate button options.

A.2.2 User Management Module

The User Management module clearly designates the privileges of the user, their access rights, which pages a user is allowed to view and the pages in the application that a user is denied access. This information is managed by use of SESSIONS in PHP, which typically act as a global variable. When a user successfully logs in, his/her access rights, which can be Admin/Viewer/Site Manager, is retrieved from the Database and is stored in a SESSION variable.

When a logged in user is found to be an administrator they will be provided with a special option in the navigation bar that allows him/her to enter an administrator only page, where approvals/denial of requests are made. This option is not given to any other user in the

system on login. This user has access to all the three modules of the system; the View Module, any user options in User Management Module and Content Edit Module.

When a logged in user is found to have only viewer privileges, he/she will have access only to the View Module. This user is typically an end user of the system, who directly uses the information in the system for his/her construction business but can not alter the information presented in the KyTCBIS. Sufficient information is provided by the system, which even specifies to the user, which materials can be used for what kind of applications and the test results provided will give answers to how conclusions on the effectiveness of a byproduct are arrived at.

If the user is found to be Site Manager, he/she will have access to both the View Module and the Content Edit Module. On successful login, this user will be provided with options to reach the System content edit section, through the Left navigation column. A Site Manager on entering the Content edit section can view only the sites he/she manages and edit any information pertaining to those sites. The restriction on Site Manager, in allowing him/her to view only the sites he/she directly manages is provided by the intricate functionalities in the User Management Module. In addition to editing the existing sites managed a Site Manager can request for new sites to manage through the User account setting provided in the top right corner on each page.

A.2.3 Content Edit Module

The Content Edit Module is primarily used by the Site Material Managers and Data Entry Operators. When a user enters this section of the system, the sites the user has privileges to manage will be available to edit. Modifications can only be made by users whose privileges allow them to edit the given site. The sites available are determined by a function call to siteaccess() in connect.php file, which is stored in Sites in a set of session variables. These variables should be used by the scripts in the Content Edit Module to determine which sites should be open for modifications by the user.

A.3 Users

The KyTCBIS is structured in such a way that any user who wishes to use the system needs to register by giving their credentials in a system registration form. The different types of users in the system are Viewer, Data Entry Operator, Site Material Manager, and System Administrator.

A.3.1 Viewer

A user who registers with a viewer status will have access to view all the information in the system pertaining to the plants in Kentucky, the byproducts they produce and their properties. This user will not have access to view any information pertaining to Site/Material Edit section or will have any options to view Administrator section.

A.3.2 Data Entry Operator

The Data entry operator is the one who acts as a subordinate of the Site Manager and will have access to edit the Sites that his/her site manager manages. However, they won't have access to request establishing new sites. This user, like any other authorized users in the system will have access to Site/Material View module of the system.

A.3.3 Site Material Manager

This user will have the option to request the sites he wishes to manage in the system and takes the responsibility of adding/editing/deleting information pertaining to the Site he is authorized to manage. A Site Manager can also request new sites that he wishes to manage from his account settings on successful login. Any request related to creation or request for new site to manage, requires an approval from the System Administrator. This user, like any other authorized users in the system will have access to Site/Material View module of the system. A Site Manager will/should also have the option to authorize a new Data Entry operator from his Account Setting section (located at top right on each page). Any Authorized Site Manager on successful login will have access to reach his/her Site/Material modification section. This option is will be given in the navigation bar.

A.3.4 System Administrator

The system administrator manages the entire system. There can be any number of administrators in the system. However any new Administrator request requires an approval from one of the existing Administrators. This user will have access to any page in the system. When a System Administrator logs in, a special link option will be available for him/her in the navigation bar that allows him to access the Administrator section of the System, where options will be available to accept or deny a request from Viewer/New Site Manager/Existing Site Manager Site Request/New Admin Request etc.

A.4 Table Structure

When developing the KyTCBIS, the relational system for the SQL database had to be researched, designed and implemented. This section demonstrates and explains the tables' structure of the KyTCBIS. Please note that the Material Table is in both the User Tables and the Content Tables. The Material Table is the link between the two table systems.

A.4.1 User Tables

User Tables are the tables in the database that pertain to users. These tables range from temporary tables for verification requests to the site and material tables. The diagram in Figure 15 shows the fields and relations of the User Tables.

Figure 15. User Tables Diagram

A.4. 2 Content Tables

Content Tables are the tables that hold the actual data of the KyTCBIS. These Content Tables, Figure 16, are very intricate and should be treated accordingly. This diagram shows the fields and relations of the Content Tables.

A.5 Installation of the KyTCBIS

To install the KyTCBIS on a Hosting Server the following steps must be followed. If there is a known alternative to software that is used it will be stated.

A.5.1 Step 1

Install, update, and patch one of the following operating system on the computer to be the Hosting Server.
- Windows
- Linux
- UNIX

Figure 16. Content Tables Diagram

- OSX
- Solaris.

A.5.2 Step 2

Acquire the following install files for the corresponding operating system that was chosen in Step 1.
- Apache 2
- PHP 4
- MySQL 4

A.5.3 Step 3

Install the packages in the following order using the README files that are in each package
- Apache 2
- PHP 4
- MySQL 4

A.5.4 Step 4

Copy all of the files in the provided Site directory to the root of your web server.

A.5.5 Step 5

Take the "temp1.sql" file that is in the provided Site directory and using any SQL import program, upload it into your SQL server. This will set up the Tables for use in the KyTCBIS.

A.5.6 Step 6

Use a plain text editor (NOT WORD) to open the connect.php file in your root directory. Then change the $username, $database, $server and $password variables to allow the KyTCBIS access to the services it needs.

A.5.7 Step 7

If you want the main page Google Map to work you will need to apply for a key at www.google.com and place the key in the $key variable in the connect.php file.

A.5.8 Step 8

Login to the system using the user ID: admin and a blank password. From here you can use the user administration and content administration to populate the KyTCBIS.

A.6 Important Files

Some files in the KyTCBIS are very important to its operation. The files in this section can be tricky so the general algorithms have been put here to help possible future developers understand what has been completed thus far.

A.6.1 Function Scripts

A.6.1.1 Sessions.php

This file handles functions to check for different access rights of the users. Different pages in the system will require different access rights. So this script gives definition in the form of functions for Viewer, Site Manager and Administrator access. This file also acts as a log management system, which captures information about the user of the system and stores it in a log file called "logfile.txt". The other functions include displaying user option i.e. at the top of each page in the system, a user is provided with Logout option and account settings change options, these are achieved by this function. The log file can be represented in a Database for easy access and analysis. Note: This script needs to be included in all the scripts of the system at the start, for the system to work stable.

A.6.1.2 Connect.php

This script has functions that connect to or disconnect from the Database. In addition to that, it also handles function that provide Site Access limitations i.e. the function determines all the sites the current site manager or Data entry operator have access to, and stores these sites along with the count of site in session variable. This information can be accessed by the Developer to display only those sites information for editing to the Site Manager/Data Entry Operator (Typically this should be checked in all the pages where a data edit operation is done).

A.6.2 Page Scripts

A.6.2.1 Login.php

Enables logon to the System. When a user clicks on a logout button, the control gets transferred to logout.php where all the existing session variables are deleted and then control will get transferred to this login page automatically.

In logout.php, after deleting all session variables, a fresh session is again started and a logout condition is set. This makes sure that even if a user tries to click back button to view the System information, it will redirect him to the login page and prompts him/her to login again.

A.6.2.2 Registration.php

The registration.php enables users to register with the system. On registration, any form data entered by the user is stored in a "TEMPUSER" table. The data will be moved to the permanent user table "USER," only when the users activate their account by clicking on that activate link send to his/her email. For Site Manager/Administrator, the status of the user will be stored as "TEMPSITEMANAGER/TEMPADMIN" until the existing Administrator approves their request. However, once these users activate their account by clicking on the activation link in their email, they will be able to access the Site as a VIEWER.

A.6.2.3 Account.php

Enables users to change their profile, e.g. address, phone number, password etc. If the user is a Site Manager, it also allows him/her to request for a new site to manage.

A.6.2.4 Logout.php

The logout.php gets triggered when a user clicks a logout button. It deletes all session variables, and then a fresh session is again started and a logout condition is set. This makes sure that even if users try to click back button to view the System information after Signing off, it will redirect them to the login page and prompts them to login again using their Username and password.

A.6.2.5 DSite.php

This page will be the first to get displayed when a user has successfully logged in. When the control enters into this page it checks the following conditions.

Condition one is the user reaching this page, by clicking back button after logout operation, if that case is true, then the user will be redirected to the login.php page.

Condition two is the username and password provided by the user is valid, if yes the entire page gets displayed. Otherwise, the user will reach a page called "invalid.php" where there will be a mention, that the user name or password provided is wrong. Hence, in this case, the system user needs to type in their correct credentials.

This page will typically display all the "Sites" that exist in the system. It also has a crude left navigation section, which enables users to move to different sections of the Web Site. This Navigation bar needs some clarity/refinements when enhancing the GUI, to make it look elegant.

A.6.2.6 Approve.php

The approve.php can be accessed only by the authorized Administrator. An administrator will have a list of approval requests from Prospective Viewer/Site

Manager/Administrator and also from existing Site manager for new Site management.

This page, involves interaction with six (6) different tables in the database. Hence, need **careful handling if ANY MODIFICATION IS NEEDED**. Please view the file for comments on what is done on each step.

A.6.2.7 Material.php

This page can be accessed by all logged in users at any time. This page displays everything in the main window when a user is in the View Module area.

A.7 User Flow

User Flow is very important to keep users working within the system. Without proper flow a user may reach a point where they can not do what they want to do or reach a blank page or even run into inconstancies in the way the system works. This section is meant to outline specific sequences of user flow that may require multiple files and be tricky at times.

A.7.1 User Registration/Login

To use the system, any user should register. At login.php there is a link called NEW USER: "REGISTER", which leads to a user registration page. The user needs to enter their credentials in this page as all fields in the registration are efficiently validated, which include multi level validation of email field. If the validation determines an error, the error message gets displayed at the end of the page. If no error is found, the information provided by the user is stored in a temporary user table – "tempuser." The significance of storing in temporary table is described later, in this documentation.

While completing the fields, the user encounters choosing the user type. If a user chooses "Viewer" or "Administrator" or "Data entry", then no additional fields are requested. On the other hand if a user chooses to be a Site Manager, additional information is requested on clicking the "Choose Designation" button. This additional information pertains to the Site they wish to manage and other Site related information.

Once the user information is stored in the tempuser table, after validation an email is sent to the user prompting him/her to activate the account, this is done essentially to validate the user's email address. Also, an email is sent to the Administrator informing about the recent user request. Once a user activates his/her account, the information about the user in the "tempuser" table is moved to the permanent user table- "user". Thus, only when the user registration information is moved to the table "user" he/she will be able to login to the system. This way the users email address is successfully validated, since they need to click the activation link send to their email address to activate the account. Irrespective of their type (viewer or admin or site manager) users will be given access to view the information in the View module of the system once the account is activated. However, if the user is a Site

Manager or Administrator, an existing Administrator should login to the system and approve their request to Create/edit sites or to get administrator privilege respectively.

A.7.2 User Access

When a user logs in to the system, (in DSite.php – first page reached on login) a check is performed whether the user has provided the correct user name and password. If the login information is correct, then the user's access rights are stored in SESSION variable along with a SESSION variable called "grant" which is set to "yes". With these two variables set, a check can be done on each page that the user attempts to view, for their access rights. A decision is made on whether to display that page or not, based on matching the user's access rights with the minimum right required for that page. There are several scenarios that are possible on what data the user can access. This depends on the user's privilege in the system.

A.7.2.1 Viewer only Access

If the user has only Viewer access, on login, he/she will be provided with a list of sites (in DSite.php) that are maintained in the system. The user can select a site to view more detailed information, by clicking the link for that site of interest. This results in a control transfer to material.php file. This file has two drop down menus, the first menu displays the Site and its corresponding materials by retrieving data from three tables- material, materialrelation and Site. The viewer can select any particular material and can view the Engineering properties or Environmental properties or Applications of the material. Based on which button the user clicks, the corresponding information is retrieved after a control transfer to properties.php. The property the user chooses to view and the material of interest are passed to this script. Based on these values the information is retrieved from the appropriate table (i.e. from table "engrproperty" or "envproperty" or "application")

The second part of the material.php file, enables selection of material and based on the user's interest, they can choose to view the material description and/or production process and/or potential uses. Based on the user's selection of view, the appropriate information is retrieved from the table "material" and this action takes place in matdesc.php file.

A.7.2.2 Site Material Manager Access

If the user is a Site Manager: in addition to the viewers access mentioned above, the Site manager will have access to a link in the left navigation column in DSite.php, which reaches the Content Write/edit section of the system. At this point the control will get transferred to chooser.php, where at the start the siteaccess() function in connect.php is called, which stores the sites the current site manager is allowed to access in session variables. $_SESSION['sitecount'] contains the count of number of sites the current site manager manages. $_SESSION[0], $_SESSION[1],..., $_SESSION[the max count] contains the name of the sites managed by the user.

A.7.2.3 Administrator Access

If the user is an Administrator: in addition to the Viewer access and the Site manager access mentioned above, an Administrator will have a specific access in the left navigation bar called "Admin section" this option only appears when an administrator logs in. Hence this link is hidden from view or other normal users. On clicking this link, the Administrator reaches the "approve.php" script. In the approve.php script there are four different sections:

- Request for Site Manager access
- Request for Administrator access
- Request received for Viewer access
- Additional Site request from existing site manager

These requests are pulled out of the Database by calling a function "request ($type)", it takes the users type as input and displays if any request for that user type is received recently. If such a request exists, then it is display all the requests for a particular user type in a pop down menu and gives the following options for the Administrator.

A.7.2.3.1 View Request Information

A request can be viewed by the Administrator by calling the function viewuser($user,$usertype), where $user is username and $usertype is the user's type. Based on these two parameters, a user's request is retrieved from the Database table and displayed for view in the browser. The system follows the following algorithm to display the request.

If the user type is viewer or temp admin
if the user name is in tempuser, if found
display it
else if not found in tempuser table
retrieve from user table and display it.

Else if usertype is Temp Site Manager
if the user name is in tempuser, if found
display it
else if not found in tempuser table
retrieve from user table and display it.
retrieve the Site information from Site by using the tempusersite relation
and display it.

Else if usertype is existing site manager
retrieve the Site request from Site by using the tempusersite relation
and display it.

A.7.2.3.2 Approve Request

An approval can be done by the Administrator by calling the function acceptuser($user,$usertype), where $user is username and $usertype is the user's type. Based on these two parameters, a user's request is approved and hence undergoes significant changes in the database.

If the user type is tempadmin
If user information is in tempuser table
Move the user's information from tempuser table to user table and
Set the user type as ADMIN
Else if user information is already in user table
Set the user type as ADMIN

If the user type is Viewer
Move the user's information from tempuser table to user table

If the user type is temp Site manager
If user information is in tempuser table
Move the user's information from tempuser table to user table and
Set the user type as Site Manager. Also move the Site data pertaining to that Site manager from tempsite to Site table
Else if user information is already in user table
Set the user type as Site Manager. Also move the Site data pertaining to that Site manager from tempsite to Site table.

If the user type is Site Manager
Move the Site data pertaining to the existing Site manager from tempsite to Site table.

A.7.2.3.3 Delete Request

A delete can be done by the Administrator by calling the function deleteuser($user,$usertype), where $user is username and $usertype is the user's type. Based on these two parameters, a user's request is deleted and results in significant changes in the database.

If the user type is tempadmin
If user information is in tempuser table
Update the user status as Viewer
Else if user information is already in user table
Set the user type as Viewer

If the user type is Viewer
Delete the user's information from tempuser table

If the user type is temp Site manager
If user information is in tempuser table
Update the user status as Viewer. Also delete the Site data pertaining to that Site manager request from tempsite
Else if user information is already in user table
Set the user type as Viewer. Also delete the Site data pertaining to that Site manager request from tempsite.

If the user type is Site Manager
Delete the recent Site request data pertaining to the existing Site manager from tempsite.

A.7.2.3.4 Send Notification (only if the user type is "Viewer")

When an administrator clicks the send notification button for viewer, it sends a reminder to the viewer that he/she had recently made a registration, but haven't activated the account from his/her email. This email gets triggered through notifyMail($user) function, where $user is the user name to be notified.

DEFINITIONS

Some terms in this document are either abbreviated or shorthanded to allow for quicker development and reading of the document. They are all meant to be as obvious and self explanatory as possible.

KyTCBIS: Stands for Kentucky Transportation Cabinet Byproduct Information System.

PHP: Refers strictly to PHP 4, stands for Hypertext Preprocessor

Technologies: can refer to any technical item used in the KyTCBIS. Includes, but is not limited to, applications, specifications, practices, services, and techniques.

Hosting Server: Used to refer the computer (i.e. server) that will serve the HTTP requests that are requested by Client PC's.

Client PC: Refers the computer that a user will use to view, send and request information to and from the Hosting Server.

FTP: Stands for File Transfer Protocol. Used to transfer files between networked computers.

HTTP: Stands for Hypertext Transfer Protocol. The technology that is used to transfer requests and content to and from the Hosting Server and the Client PC.

User: Generic term for all users, logged in as any user type and non-logged in users, that are at a Client PC that is using the BIS.

Language: Refers to some programming language. See Interpreted Language and Complied Language

Interpreted Language: Any Language that its source code does not have to be put through any program pre run-time to be able to run. This usually means a Service on the computer running the program will interpret the source code as it is being run. This usually means all files are in plain text.

Complied Language: Any Language that its source code has to be put through a program pre run-time to be able to run. This usually means the program can be run independently of any Services on the computer. Usually means all files are Machine Code and therefore unreadable by a non-developer.

Service: A program that is running on a computer that is always running to do some task. Can be an interpreter so that the computer can run a specific Interpreted Language. Example: Java Run Time Service.

HTML/XHTML: Stands for HyperText Markup Language /Extensible HyperText Markup Language. This standard file format is generated and sent by the Hosting Server to the Client PC and is Interpreted by the Client Browser.

CSS: Stands for Cascading Style Sheets. Is used in conjunction with the XHTML. Not required to show information in the XHTML file but formats the visuals rendered by the Client Browser.

Client Browser: The program the is run on the Client PC that interprets the XHTML, CSS and JavaScript that is given to it by the Hosting Server. Examples: Firefox, Internet Explorer and Safari.

JavaScript: Is a Interpreted Language that is interpreted by the Client Browser. It can do many more things than standard XHTML but is not guaranteed to be active on a Client Browser so cannot be overly used.

SQL: Stands for Structured Query Language. Standard language used to interact with a relational database.

Hosting Provider: This is the entity that is managing the Hosting Server and the KyTCBIS.

CSV (File): Stands for Comma Separated Value File. This is a file type standard that is easily parsed and created. It has the benefit of only holding data, not formatting, equations or links. All modern spreadsheet and database programs can export their tables as CSV Files.

Module: A group of like files in the project, used as a way of dividing the programming of the project up into distinctive portions as to not overwrite or duplicate any features.

Table: Refers to the organizational units in a SQL database. These can have relations to each others fields to become a relational SQL database.

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