INVESTIGATION OF PASTE TECHNOLOGY

FOR

CCB DISPOSAL

AND MINE RECLAMATION

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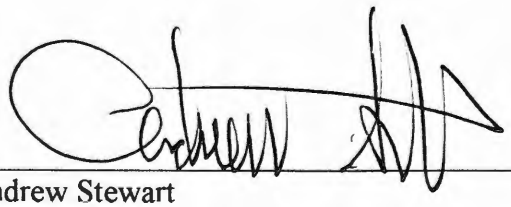

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INVESTIGATION OF PASTE TECHNOLOGY FOR CCB DISPOSAL AND MINE RECLAMATION

ABSTRACT

The focus of this proposal is the development of alternative coal combustion by-product (CCB's) handling and disposal practices incorporated with mine reclamation at Coal Creek Station and The Falkirk Mine, using paste technology. Current disposal practices involve the placement of CCB's in either geomembrane lined storage ponds or in an earthen lined landfall facility. In addition to the on-site storage, both bottom ash and fly ash are marketed and sold for beneficial use. The paste alternatives which are proposed for investigation involve the handling and placement of only fly ash as a low-moisture-content, non-segregating "paste" either as backfill for the open pit coal mine or as potential backfill for existing underground workings.

The alternative disposal concept of immediate interest is placement of fly ash in a stable paste form as backfill in the open pit. This in turn will provide an extension in the operating life of the landfill and thus delay capital costs associated with siting and permitting a new facility. A further benefit is the use of the CCB's as a backfilling agent for reclamation of the open pits. These as well as other system configurations have only been developed to a conceptual level; engineering and cost model development can only proceed after a basic understanding is developed of the chemical, physical, and rheological characteristics of the fly ash paste. The characterization program presented in this proposal forms the basis for the pre-feasibility evaluation and pilot demonstration.

We are proposing that GRE, The Falkirk Mine, En-Rock, Golder and the NDIC jointly develop the pre-feasibility evaluation and pilot scale demonstration for paste

technology at Coal Creek Station and The Falkirk Mine. This project and the development and implementation of the paste technology will enable GRE, The Falkirk Mine and the lignite industry to realize significant savings upon commissioning of a paste plant.

INVESTIGATION OF PASTE TECHNOLOGY FOR CCB DISPOSAL AT COAL CREEK STATION

1.0 PROJECT SUMMARY

The focus of the proposed project is the development of alternative fly ash handling and disposal practices using paste technology. Current disposal practice involves placement of CCB's in either geomembrane lined storage ponds or in an earthen lined landfall facility. In addition to the on-site storage, both bottom ash and fly ash are currently marketed and sold for beneficial use. The paste alternatives which have been outlined in concept involve the handling and placement of the fly ash as a low-moisture-content, non-segregating "paste" either as backfill for the open pit coal mine or as potential backfill for existing underground workings.

The alternative disposal concept of immediate interest is placement of fly ash in a stable paste form as backfill in the open pit. This in turn could provide an extension in the operating life of the landfill and thus delay capital costs associated with siting and permitting a new facility. These as well as other system configurations have only been developed to a conceptual level. Engineering and cost model development can only proceed after a basic understanding is developed of the chemical, physical, and rheological characteristics of the fly ash paste. The characterization program presented in this proposal forms the basis for the pre-feasibility evaluation and pilot demonstration.

The accomplishment of this project will provide the information necessary to begin taking full advantage alternative disposal and reclamation methods, thereby increasing the competitiveness of North Dakota Lignite (NDL) in the marketplace. The proposed project will focus on an alternative disposal method for NDL CCB's produced at GRE's

Coal Creek Station and mine reclamation at the The Falkirk Mine near Underwood, North Dakota, but the project will have a positive economic impact on the entire NDL industry.

2.0 BACKGROUND

Every year at Coal Creek Station, some 900,000 tons of coal combustion by-products (CCB's) are produced. A large quantity of this production is marketed into various applications. Fly ash is sold into the concrete market or into flowable fill markets in annual quantities of approximately 150,000 tons. Bottom ash is utilized as an aggregate or as road de-icer in quantities of approximately 75, 000 tons. Scrubber sludge is in the process of being converted into gypsum for sale and it is anticipated that after development of markets, no disposal will be required. The unutilized portion of the CCB's produced at the Coal Creek Station site are disposed of in lined disposal facilities. This project is focused on the CCB's destined for disposal and their use in the reclamation process.

The project team has a proven track record with the successful application of paste as one component in a wide range of services related to mine reclamation and mine waste disposal. The concept of making paste for the purpose of disposal in conjunction with reclamation has to be evaluated together with a number of complex issues on a site-specific basis.

In recent years much of the focus of mining research has shifted to both surface and underground disposal of mine waste. This has become increasingly more important to the overall economic viability of any given project. The integration of the mining waste disposal process into the overall project using paste technology has been a significant

recent development. The extensive experience gained from the hard rock mining industries can be directly transferred to the coal mining industry and the related power generation industry.

Application of paste in the underground environment is well documented. More recently, there has been increasing awareness of the operating and environmental benefits of applying paste production and placement concepts as alternatives to the traditional placement of granular waste products in slurry form. Water conservation, increased flexibility in facility siting and reductions in the risk posed by impounding liquids are among some of the most compelling reasons why paste and its associated surface placement concepts are generating interest outside of the mining industry. While individual designs for surface paste placement facilities still require focused engineering study and judgment, the properties of the paste accommodate a much broader range of handling and placement options.

The overall economics of paste production and the benefits to the project (both short and long term) must be carefully evaluated as part of a decision to implement a paste disposal scheme. Integral to this process is the characterization of the waste material in terms of its ability to behave as a paste. The main criteria, which must be met, are:

- A sufficient proportion of fine particles to develop adequate surface tension and water-retention in the soil matrix.
- The ability of the material to maintain a non-segregating form when brought to rest (unlike typical slurry, which requires transportation above some 'critical' velocity in order to prevent settlement).
- The capacity of the material to be transported in a pipeline.

As part of the research and development of this technology, we have developed a systematic, phased testing program to fully evaluate materials and determine how to produce the highest quality, lowest cost paste backfill that will meet the operating, geotechnical, waste disposal and health and safety needs for a given site. This program utilizes a series of specially developed laboratory index tests that are used to evaluate the potential of different materials for paste fill transport. Complementing this is access to the latest state-of-the-art laboratory equipment for material property determination required for dewatering potential, transport flow, and backfill strength generation.

If the criteria for paste behavior are met, preliminary design work can proceed, and includes the following components:

- Define the level of dewatering necessary to produce a paste of ideal consistency for the project.
- Evaluate a range of paste production and transport technologies to determine the most cost-effective process design.
- Evaluate the geotechnical properties of the fly ash paste and develop appropriate placement and stabilization schemes.

As a part of the team, Golder is at the forefront of this emerging paste technology. Their extensive project experience includes involvement in the design, construction, and commissioning of most of the operating paste backfill systems in Canada. This Canadian project experience will directly benefit GRE and The Falkirk Mine as Coal Creek Station has similar winter operational design constraints. They are presently involved in the detailed engineering design of paste systems for BHP, Cannington Mine in Australia and Caraiba Mine in Brazil as well as the conceptual and preliminary engineering design of several paste systems in the U.S., Canada and Europe.

En-Rock, through its work with the CCB's from Coal Creek Station has extensive knowledge of the disposal methods currently in use as well as with the engineering characteristics of the CCB's. Their knowledge of disposal costs and state regulations regarding disposal of solid wastes is an important part of the testing and design process.

3.0 PROJECT DESCRIPTION

3.1 Introduction

We are proposing that GRE, The Falkirk Mine, En-Rock, Golder and the NDIC jointly develop the pre-feasibility evaluation and pilot scale demonstration of paste technology for CCB disposal and mine reclamation at the Coal Creek Station site. This proposed project reflects a commitment to the development and implementation of paste technology enabling GRE, The Falkirk Mine and the lignite industry to realize significant savings upon commissioning of a paste plant.

3.2 Goals and Objectives

The project objectives include the following:

- Determine the basic physical properties of the fly ash material which contribute to the capacity to produce a low-moisture content paste;
- Determine the geotechnical properties of the fly ash in paste form and evaluate the effects of these properties on handling, transport and placement in a designated surface disposal facility;
- Evaluate the geochemical properties of the fly ash paste and associated factors related to its environmental performance and capacity to meet regulatory requirements;
- Demonstrate the environmental stability of Coal Creek Station CCB's both in the laboratory and in a pilot scale field test; and

- Support the reclassification of Coal Creek Station CCB's to allow for placement in the open pits as an integral part of reclamation.

The reduction in operating and reclamation costs associated with this alternate disposal technique can provide significant savings to GRE, The Falkirk Mine and the Lignite Industry.

3.3 Project Approach

Section 3.4 of this proposal presents the overall technical approach to each of the disciplines. The first task involves a literature review and evaluation of available data. Because there is a large volume of technical information, including specific studies conducted for Coal Creek Station and research conducted on North Dakota Lignite, we believe that this task is critical to the refinement and development of specific scopes of work for each discipline. The technical approach involves an initial literature review and data evaluation for each discipline, followed by co-development of a specific scope of work with GRE and The Falkirk Mine personnel familiar with the issues. We believe that this co-development of the scope of work will reduce the overall labor effort and provide GRE and The Falkirk Mine with the ability to direct each task under each technical discipline. If a "fatal flaw" is discovered during this literature review and evaluation, changes to the project scope could be made in a timely fashion and cost impacts could be minimized.

Based on the current understanding of the geochemical and geotechnical properties of the fly ash generated at Coal Creek Station, we believe that we have

a good chance for demonstrating the environmental stability of CCB paste. The technical approach to the project includes regulatory issues, environmental siting issues, geotechnical characterization, engineering, geochemical characterization, hydrogeologic characterization, reclamation issues, and construction of a pilot scale field test to further demonstrate the environmental stability of CCB paste.

GRE, The Falkirk Mine, En-Rock and Golder have similar approaches when it comes to regulatory issues. Due to the personal working relationships that GRE and The Falkirk Mine employees have developed with regulatory personnel, together with their knowledge of the regulation themselves, we will look to GRE and The Falkirk Mine for assistance in developing the approach for addressing regulatory issues. Given the critical nature of these discussions and the time involved with the "educational process", this process will be initiated early in the project.

3.4 Methodology

3.4.1 Permitting and Environmental Issues

As mentioned previously, Golder and En-Rock plan to capitalize on the good working relationship between GRE and The Falkirk Mine and the NDSDH. We will work closely with GRE and The Falkirk Mine in developing an approach to the waste reclassification and permitting.

The general framework of the technical approach would be as follows. Results of the bench-scale testing will be extended to predictions of the system

performance through the use of industry-accepted groundwater and geochemical numerical modeling methods. The results of the pilot test will also be used to further calibrate the numerical models and allow their use in predicting the environmental impacts of paste disposal at the site with greater confidence. This sequential refinement of environmental models to enhance their predictive capabilities and support permitting efforts has been used with consistent success with agencies around the world. The quality of the supporting data provided by actual field trials helps to ensure regulatory acceptance of the findings.

3.4.2 Geotechnical Characterization

In order to systematically evaluate the potential for surface paste placement, we are proposing an initial physical characterization program which will form the basis for subsequent engineering and design studies. The material characterization program would include a suite of bench-scale tests which would provide an overview of the rheological behavior of the fly ash when formed into a paste.

3.4.2.1 Review of Existing Data

As part of the geotechnical characterization, we will conduct a review and evaluation of geotechnical testing that has been completed on Coal Creek Station CCB's. This literature review and evaluation effort will result in an optimization of previous studies and test results. Following this literature review and evaluation, we will determine the specific testing

required to evaluate the geotechnical behavior of paste formed from Coal Creek Station CCB's.

3.4.2.2 Physical Paste Characteristics

Samples of typical Coal Creek Station fly ash will be prepared and mixed in a range of workable consistencies as determined from the ASTM standard 12-inch concrete slump cone. This will allow us to determine the moisture content of the fly ash paste as a function of slump and to make a general qualitative assessment of the potential to produce a low-moisture content, non-segregating mixture (paste) from the anticipated production fly ash samples. Particle-size distributions will also be determined for an appropriate number of samples and will be used along with the workability tests to provide additional evidence of anticipated paste behavior. The bulk density, moisture content and workability determinations will be supplemented by a series of index tests to provide an indication of the void ratio and degree of saturation of the paste at a given level of workability (slump).

The results of this preliminary evaluation will provide recommendations for any changes to the balance of the planned testing regimen. The evaluation will also serve to identify a number of fly ash transport systems which either alone or in combination with existing process infrastructure could be considered as the primary candidates for further evaluation.

3.4.2.3 Geotechnical Properties

Geotechnical testing will be carried out to identify some of the important factors, which influence the approach used to develop surface paste placement alternatives. In particular, the test data generated during the preliminary geotechnical evaluation will allow for objective assessments to be made of the stability of fills created from fly ash paste. Consequently, the geotechnical characterization program is heavily oriented toward strength development and consolidation characteristics. Due to the anticipated consistency and relative strength of the fine-grained fly ash paste, vane shear testing in combination with standard or seepage-induced consolidation testing is expected to be most appropriate. Traditional triaxial shear testing will also be carried out to supplement the vane shear test data and to allow for a wider range of stability models to be considered during future evaluation.

The liquefaction potential of paste is of particular interest when considering surface placement and its evaluation is based on results of the strength and consolidation test program as well as the results of permeability/void ratio determinations which can also be derived from the test data. The results of the geotechnical characterization will figure prominently in the development of placement concepts, which in turn, will drive estimates of construction costs.

The following specific program of geotechnical testing is anticipated at this time. Further refinement will be based on the results of the literature review.

- Standard one-dimensional consolidation testing;
- Specialized slurry consolidation testing to simulate field conditions and establish parameters for projecting field densities;
- Proctor compaction testing to determine moisture/density relationships;
- Vane shear testing of paste mixtures at various stages of hydration; and
- Triaxial strength tests of fully hydrated samples.

Paste amendment with binders such as Portland cement or other products will not be considered at this phase of characterization, which is intended to focus on paste in its basic form.

3.4.2.4 Hydraulic Conductivity

Hydraulic conductivity of the paste will be measured to quantify the rate of movement of groundwater and precipitation through the paste. This information will be critical to the environmental modeling, the design and evaluation of the pilot test, the calculation of potential leachate generation rates, and for demonstrating environmental stability. Saturated hydraulic conductivity will be measured in the soils laboratory on paste samples using a flexible wall permeameter (ASTM method D5084). This

apparatus is generally capable of measuring hydraulic conductivities above 10^{-10} cm/s.

3.4.3 CCB Geochemistry

To determine the environmental stability of the fly ash paste mixtures, the paste and any additives must be characterized geochemically. Although the components of a comprehensive geochemical characterization program may vary based on site-specific conditions and requirements, in general, the following elements are anticipated:

- review and evaluation of existing data;
- chemical analysis;
- mineralogical analysis;
- analysis of environmental stability.

A range of geochemical characterization will be performed to meet several objectives. A brief overview of each type of testing, its purpose, and its applicability to the project is provided below.

3.4.3.1 Review and Evaluation of Existing Data

The first task of the geochemical characterization program will involve review and evaluation of relevant information on the project, such as the nature and quantity of the anticipated waste streams, site hydrogeology, baseline environmental data, and regulatory requirements.

This information will be used to assess the need for further characterization as well as the nature and scope of any such testing.

Existing analyses of fly ash from the site will be reviewed for temporal and compositional variability. The compositional variability of the fly ash will need to be evaluated to demonstrate representative sampling for the paste testing. Existing data on leachate composition generated from standard leaching procedures will also be included in the review. To the maximum extent practicable, existing information on fly ash will be used to limit the scope and associated costs of the paste characterization program.

3.4.3.2 Chemical Composition

The team will review the available data on fly ash. It is assumed that this information will be provided by GRE from previously completed work. This information may suffice from the characterization perspective if it is determined that no additives to the paste are necessary. However, limited chemical analysis may need to be conducted on any additives potentially included in the various fly ash paste mixtures if not already available from the GRE data. In addition, chemical characterization of fly ash/additive mixtures may be necessary if it appears that chemical reactions between fly ash and binder may result in a significant change in overall chemistry (e.g., through evolution of gases).

If additional testing is required, whole rock chemical analysis (elemental composition) of the paste and/or additives will be performed

with following goals: 1) provide a reliable baseline for future study, if needed, 2) determine potential environmental impacts (i.e. those related to leachability), 3) determine compositional variability, and 4) provide an adequate database for possible geochemical modeling. To determine the chemical composition of the paste, the samples will be analyzed using a rigorous digestion method, thereby assuring analysis of an extract that represents the total sample, or using x-ray fluorescence (XRF).

3.4.3.3 Mineralogical Testing

Mineralogical testing will be performed to identify the mineral phases that make up the fly ash mixtures. The nature and abundance of the various minerals present can have major repercussions with regard to the environmental stability (e.g., leachability) of a paste material. Initial mineral identification is generally conducted using x-ray diffraction (XRD), which is a technique that has a detection limit of approximately 2 to 3 percent by weight. If more sophisticated analysis is required, use of optical microscopy and/or scanning electron microscopy (SEM) may be necessary.

3.4.3.4 Environmental Stability

Environmental stability is typically evaluated using both short- and long-term leach testing. Each is described below. Analytical requirements for the leach testing will be determined based on a review of available information and applicable regulatory requirements.

Existing information on leach testing performed in other GRE studies will be evaluated for its appropriateness, relevance, and applicability, and will be utilized to the maximum extent available and possible.

3.4.3.4.1 Short-Term Testing

Short-term testing is useful for predicting the quality of water that results from short-term interaction between water and the paste. In addition, such testing can be extended to the prediction of surface runoff quality and allow for comparison with allowable effluent limits. One test commonly used for this purpose is the SPLP test (Synthetic Precipitation Leaching Procedure, EPA Method 1312), which is designed to determine the mobility of chemical constituents by simulating interaction between meteoric water (i.e. rainwater) and a solid.

3.4.3.4.2 Long-Term Testing

The potential for generation of a high-metal leachate may also be evaluated. However, the likelihood of such a leachate being generated, and the rate at which this would occur, are not at all addressed by short-term testing. Therefore, evaluation of long-term behavior may be required.

Various laboratory methods (e.g., humidity cell testing) are available to assess long-term leachability. These tests subject the materials of interest to artificially enhanced weathering under simulated site-specific conditions (e.g., solid to solution ratio, temperature, grain size distribution of the solid, nature of the leachant, etc.). These tests are typically conducted for a minimum of 12 weeks, with the total duration depending on the material's reactivity and site-specific requirements for simulation of the natural environment.

3.4.4 Hydrogeology and Groundwater Chemistry

Hydrogeochemical characterization will focus on the subsurface environmental setting and will be performed with the following goals:

- Support any regulatory issues, including permitting, associated with the paste technology;
- Develop and implement an efficient monitoring program for the pilot demonstration;
- Establish the basis for an efficient monitoring program for full-scale operation;
- Evaluate and demonstrate chemical compatibility of the paste with local groundwater;
- Address pit dewatering issues during paste placement, if necessary; and
- Support future applications of paste for water management at the site.

3.4.4.1 Review and Evaluation of Existing Data

In accordance with the approach outlined in Section 3.4, a phased approach will be followed in the hydrogeochemical characterization. The first phase will consist of a complete review and evaluation of existing information and analyses to be provided by GRE and The Falkirk Mine including the following:

- Geology
- Hydrostratigraphy
- Hydraulic properties of hydrostratigraphic units
- Directions and rates of groundwater flow
- Groundwater monitoring (e.g. types, locations, frequencies)
- Groundwater chemistry
- Mineralogy of hydrostratigraphic units
- Local surface water chemistry (as necessary)
- Local meteorology
- Mine water management and pit dewatering operations

The team will evaluate the existing information and analyses to determine what additional interpretations or data are required to meet the objectives of the project. A general description of possible issues to be addressed and the approach to each issue are provided in the following sections.

3.4.4.2 Hydrogeochemical Conceptual Model

A conceptual hydrogeochemical model will be developed based on the past investigations, through meetings and discussions with mine personnel, and data compiled and evaluated during the review of existing data. This model will be the foundation for all decisions and investigations involving the hydrogeochemistry of the project.

A conceptual model is an integrated understanding of the geology, hydrogeology, and hydrochemistry of the site. The model is developed by integrating all three disciplines to create a unified and coherent understanding of the site that is consistent with as much of the existing data as possible. In addition to the model itself, the process of developing a conceptual model is useful and can help identify data deficiencies, model deficiencies and inconsistencies, and other valid models for the site. This will be critical to the successful development of the groundwater monitoring program and for possible applications of paste for groundwater management.

We believe that a valid site-wide conceptual model of the site already exists and is documented in the original site Environmental Impact Statement or similar documents. The team will meet with mine geologists, hydrogeologists, and environmental managers and interpret available data to extrapolate and/or refine this conceptual model to a smaller site-specific scale at potential paste locations.

3.4.4.3 Operational Aspects for Pit Dewatering

One important issue for paste application is water management during placement of the paste in the pits. Groundwater and precipitation that enter the pits can potentially mix with the paste and interfere with geotechnical properties and chemical behavior of the paste. Dewatering will need to continue throughout placement so that optimum paste properties can be maintained during and after placement.

The ideal method for pit dewatering for paste placement may differ from that currently practiced by The Falkirk Mine for GRE. We understand that pit dewatering is conducted by trenching at the base of the high-wall. This method of pit wall gravity drainage may present certain operational constraints to paste placement. The team will work with The Falkirk Mine and GRE, as necessary, to develop additional or alternative pit dewatering practices, as necessary.

3.4.4.4 Determination of Chemical Compatibility

GRE and The Falkirk Mine will likely be required to make a demonstration to the regulators about the chemical compatibility of ambient groundwater with the paste. This demonstration would address issues regarding the chemical behavior of the paste in the short- and long-term. While the issue of chemical compatibility to existing groundwater conditions will be addressed under kinetic testing described in Section 3.4.3, the compatibility with future groundwater conditions may need to be

evaluated and demonstrated. The evaluation will include an evaluation of existing groundwater chemistry data, pit dewatering chemistry data, and mineralogy of the hydrostratigraphic units.

3.4.4.5 Environmental Fate of Leachate

The environmental fate of leachate potentially generated from paste may need to be addressed depending on 1) the results of the paste geochemical characterization, 2) the compatibility of groundwater with the paste, and 3) demonstrations required by regulators. The environmental fate of leachate refers to processes that affect the movement and ultimate disposition of solutes in the aquifer. These processes include sorption and other chemical reactions, abiotic and biotic degradation, and advection/dispersion.

The final paste material will most likely exhibit a low permeability (probably around 10^{-9} to 10^{-10} centimeters per second), and therefore will conduct water at very small volumetric flow rates relative to groundwater. Consequently, it is envisioned that the fate and transport analysis will involve no more than simple mixing calculations to show that any leachate generated from the paste will be quickly diluted by groundwater, and that potential impacts to groundwater will be insignificant or non-existent.

3.4.4.6 Groundwater Monitoring

Groundwater monitoring is an important issue for both the pilot-scale demonstration and long-term fly ash paste disposal. The scope of activities in this project is limited to monitoring in-situ performance of the paste during the pilot-scale demonstration. The geochemical characterization, as well as the performance of the pilot-scale demonstration, will provide the basis for identifying future monitoring needs during full-scale operation.

The primary objective of the monitoring program during the pilot-scale demonstration is to evaluate the hydrochemical response of groundwater to placement of paste in a controlled environmental setting. A secondary objective is to guide operation of the pilot demonstration, specifically in terms of water levels.

3.4.4.7 Groundwater Management Applications

We understand that GRE and The Falkirk Mine are interested in fly ash paste for groundwater management applications at the site. These potential applications, although outside the scope of this project, may have some bearing on the types and extent of investigations conducted during the hydrogeochemical characterization. Therefore, groundwater management issues and objectives will be discussed with GRE and The Falkirk Mine at the conclusion of the review of existing data. It will then be determined what, if any, additional activities are required during this

project to support future groundwater management applications with paste technology.

3.4.5 Pilot Demonstration

The purpose of the pilot demonstration is to demonstrate the feasibility of paste technology for fly ash disposal at the site. Specific objectives of the demonstration are to:

- Perform paste placement in the real environment;
- Characterize the geotechnical properties of the paste in a simulated placement environment; and
- Evaluate the environmental stability of the paste in a simulated subsurface environment.

3.4.5.1 Pilot Design

The proposed pilot-scale test will simulate full-scale production conditions to the best extent possible. We are proposing the construction of three test cells within the existing section 25/26 lined fly ash disposal landfill. A conceptual profile of the first and second cells is shown in Figure 2, located in Appendix C. Each cell will contain various layers to include (in ascending order) pit floor material, a sand or bottom ash zone, paste, an overlying sand zone, overburden, and topsoil. However, the actual design may vary based on site-specific considerations, requirements, and limitations with respect to implementation. Cell 3 will be a control cell

constructed without paste in order to characterize the effect, if any, of the cell construction materials on groundwater chemistry. Each layer will be constructed in a manner consistent with the methods to be used during full-scale operation. Cells 1 and 3 is anticipated to be constructed in June of 1999 or as soon as practicable. Cell 2 will be constructed in at the same time, but will be reserved for filling until winter of 1999 to demonstrate paste placement under winter conditions, and evaluate paste behavior during and after an extended cold weather period.

Groundwater flow will be simulated through each cell by inducing a hydraulic gradient comparable to that under estimated reclaimed, steady state conditions. Groundwater will be added to each cell by a perforated header pipe and will exit through a single outlet pipe, as shown in Figure 2. The flow rate through the system will be adjusted to simulate estimated paste/groundwater contact times under reclaimed, steady state flow conditions. However, it may be necessary to enhance the groundwater flow velocity relative to that under natural conditions in case flow is too sluggish to result in meaningful observations over the duration of the field testing.

3.4.5.2 Paste Production System

A paste production plant must be designed around the properties of the material that will be used to produce the paste mix. These properties

will define the material handling and weigh systems and the mix system used in the plant.

There are two basic plant designs, which are defined by the mix system used to produce the paste. Continual mixing systems use an on stream monitoring system to correctly proportion the different paste mix components. The continual paste mix plant requires higher maintenance to keep calibrated and the feed material must be consistent in size distribution and moisture content to produce a constant slump paste product. Continual mixers can not respond quickly enough to variations in feed material properties to prevent an incorrect slump product from being produced.

A batch mix paste plant design uses simple weigh hoppers to accurately proportion each of the materials that make up the paste backfill. By combining a volume measurement with the weigh measurement in the weigh hopper, the paste mix can automatically be adjusted by the plant instrumentation to compensate for variations in the size distribution and moisture content of the materials used to create the paste mix.

3.4.5.3 Pilot Scale Paste Mix Systems

The initial geotechnical characterization of the fly ash will include the preparation of various mix designs based on the dry weight of materials. Due to the limited amount of paste required for the pilot field test, we envision that mixing could be accomplished with either a mobile

concrete mixer or a ready-mix truck. With the mobile concrete mixer the fly ash is augured onto a weight belt, and a metered amount of water is added. Mixing time is limited to the time the materials spend in the auger. Ready-mix trucks could be utilized with the mixing accomplished at a central plant, or in the field using volumetric measurements. If required, a concrete pump truck will be used to facilitate placement.

3.4.5.4 Placement Characteristics

As part of the geotechnical characterization program, the design of various paste mixes will include an evaluation of placement characteristics. As with concrete placement, field slump tests will be conducted regularly to evaluate both the workability and relative moisture content of the mix when placed. The results of the slump tests will be compared to the laboratory test work to correlate predicted field performance. As with concrete, a slump test is a good indicator of moisture content in the paste, workability, permeability, and strength of the material.

3.4.5.5 Instrumentation and Monitoring

Monitoring of each test cell will be accomplished with three monitoring wells installed by drilling after cell construction. The wells will be constructed, as shown in Figure 2, located in Appendix C, to monitor groundwater chemistry and levels in the underlying pit floor material, in the sand zone at the paste surface, and in the overlying overburden. Samples

will be collected and analyzed at a frequency to be determined from the short-term and possibly long-term laboratory testing results.

Samples of the paste will also be collected in standard concrete cylinders for strength and possibly permeability testing. This testing will be used to confirm that the field mix meets design requirements and to support additional numerical modeling efforts.

3.5 Financing

The financing of the portion of the project not funded by the NDIC will be provided by Great River Energy or through other arrangements.

4.0 STANDARDS OF SUCCESS

The standards of success for this project parallel the benefits to the State of North Dakota as described in Section 6.0 below. To reiterate, these include:

- The ability to decrease or eliminate transport and disposal of the CCB's in the current landfill which result in extending its operating life;
- The ability to engineer and place a low permeability barrier in the open pits to influence groundwater movement;
- The ability to engineer the placement of the paste, i.e., as backfill for the reclamation of the open pit or as underground fill to minimize subsidence problems associated with old underground mine workings;
- The potential to accelerate reclamation of mined areas;
- The potential for utilizing the fly ash in paste form to create a cap and cover system for the existing settling pond as an integral part of a long-term closure and comprehensive reclamation/alternative land use plan; and

- Avoid taking land out of production by reclaiming it for beneficial agricultural use, instead of creating disposal sites.

5.0 QUALIFICATIONS

The team of Golder/En-Rock provides Great River Energy, The Falkirk Mine and the NDIC with an unparalleled history and capability of services relevant to both paste backfill technology and solid waste disposal and permitting. Our reputation and long history of performance will dramatically enhance the ability to successfully modify the regulatory environment to accommodate the conversion of fly ash material into a paste for placement at an unlined facility, thus saving time and cost while enhancing the environmental benefits including reclamation of these areas. Our landfill design engineering capabilities developed over decades of service to the solid waste marketplace and our position in support of the international mining sector provide global perspective and capabilities that cannot be duplicated by any other firm. Further, with Golder's wholly owned subsidiary, Paste Technology Ltd. (PasteTec), the team has the organizational infrastructure to support specialized testing and support services that may be required as a result of our discussions with the regulatory community. We have mobilized a premiere team of engineers and scientists to support this project, as we believe the opportunities for the NDL Industry, Great River Energy, The Falkirk Mine, Golder and En-Rock are immense through the coming years.

Golder has placed an expanded interest upon power industry needs since the late 1980s, identifying key issues and concerns facing that industry and providing unique value added strategies to address those issues. A history of success has developed from the application of skills and services developed from other market sectors that include solid

waste and mining. A primary area of concern facing both the mining and power industries involves the long-term disposal of waste materials in an economical and environmentally appropriate manner. Towards that end, we have invested heavily in the development of PasteTec to provide alternative disposal methods to the mining sector around the world. Those investments have resulted in substantial changes at a number of mining operations, whereby waste materials have been accessed and utilized for beneficial uses. This has frequently resulted in lowered operational costs through the use of the paste backfill for engineering purposes or to reduce the long-term costs associated with the closure of a waste facility. We are now proposing to bring this technology to the coal fired power industry to provide an alternative disposal of fly ash materials.

Through Golder/En-Rock's long relationship with Coal Creek Station personnel, we have been impressed with the application of innovative technologies and understanding of the characteristics of the fly ash that is generated by your facility. We believe Great River Energy will continue that tradition and be one of the most forward looking operations in the United States with respect to both the above criteria. We have also been impressed with the "teaming" approach to working with the State regulatory community. We consider this relationship to be vital to the success of permitting efforts with the NDSDH. Based upon meetings already held with Coal Creek Station, The Falkirk Mine personnel and state agencies, Golder/En-Rock continues to believe in the mutual opportunities for the NDL Industry, Great River Energy, The Falkirk Mine, Golder and En-Rock.

6.0 VALUE TO NORTH DAKOTA

The primary benefit to North Dakota and the Lignite producers is the economic benefit that can be realized by utilities when the disposal of the high volume of CCB's can be incorporated into enhanced reclamation efforts. This in turn benefits the environment, reduces mining and power production costs and returns land to productive use after mining. From the perspective of the state's lignite industry, alternative CCB handling and disposal systems combined with enhanced reclamation efforts has the following potential benefits:

- The possibility of decreasing or eliminating transport to and disposal of the fly ash in the current landfills which would result in extending operating lives;
- The ability to engineer and place a low permeability barrier in the open pits to favorably influence groundwater movement;
- The ability to engineer the placement of the paste, i.e., as backfill for the reclamation of the open pit or as underground fill to minimize subsidence problems associated with old underground mine workings;
- The potential to accelerate reclamation of the mined areas;
- The potential for utilizing the fly ash in paste form to create a cap and cover system for the existing settling ponds as an integral part of a long-term closure and comprehensive reclamation/alternative land use plan; and
- Avoid taking land out of production on a permanent basis by reclaiming it for beneficial use, instead of creating disposal sites.

7.0 MANAGEMENT

The proposed project will be managed and coordinated by Mr. Andrew Stewart of En-Rock, Inc. Mr. Stewart will also be responsible for aspects of the project dealing with disposal costs, CCB characteristics and solid waste regulations. Mr. Stewart has degrees

in Chemistry and Civil Engineering and is a registered professional engineer in North Dakota and Minnesota. He has over 20 years of experience in the engineering and construction fields, with 17 years at Cooperative Power, with responsibility for by-products at Coal Creek Station. He is the immediate past chairman of the board of the American Coal Ash Association and was recently named as an honorary member of the European Association for Use of the By-Products of Coal-Fired Power Stations. Mr. Stewart is very involved in all aspects of by-product utilization and testing.

The Golder portion of the project will be managed and coordinated by Mr. Ron Jorgenson. Mr. Jorgenson has over 18 years of professional engineering experience and has been responsible for management, coordination, and administration of industrial, commercial and highway heavy construction projects from conceptual stage through construction including; engineering and design, estimating, bidding, negotiating contracts, scheduling, along with the monitoring and reporting of construction progress. As a senior project manager with Golder Mr. Jorgenson has been responsible for the preparation of geotechnical and hydrogeologic reports including their field investigations. Mr. Jorgenson has served as the project manager for large and technically diverse geotechnical projects for mining, general civil, and waste management clients.

Other key Golder staff members and their areas of expertise are as follows:

Mr. Scott Miller - Permitting and Environmental Issues

Mr. Miller is an Associate with Golder and has over 10 years of experience in geological engineering and geological investigations, related to environmental issues and permitting. Mr. Miller has specific experience in the following areas:

- Environmental Impact Statements;

- Waste Discharge Permits;
- Air Quality Permits;
- Surface Mining Permit and Bond Calculations;
- Waste Characterization Studies; and,
- Water Resources Monitoring Plans.

Dr. Rens B.M. Verburg - Paste Geochemistry

Dr. Verburg is an Associate and Senior Geochemist with over 10 years of experience in geochemical analysis of contaminant behavior. Dr. Verburg has been involved in a considerable number of studies on contaminant fate and transport at industrial facilities in the United States and abroad. Dr. Verburg is experienced in evaluating geochemical controls on metals mobility and bioavailability through use of innovative investigative techniques and advanced hydrogeochemical modeling. Dr. Verburg has designed, executed, and reviewed numerous programs aimed at determining the environmental stability of paste materials. In the course of these investigations, Dr. Verburg has developed and implemented bench- and pilot-scale projects for stabilization of paste materials, and has been retained as a technical expert to provide litigation support.

Mr. Matthew P. Wickham - Hydrogeology/Geochemistry

Mr. Wickham is a Senior Project Manager with more than 14 years experience in hydrogeology and geochemistry. Mr. Wickham has worked on large multidisciplinary projects involving hydrogeologic and geochemical characterization of water resources for water supply and water rights adjudication, aquifer restoration and remediation design and

evaluation, investigation of acid rock drainage, aquifer protection permitting, isotopes as environmental tracers, and development and application of analytical and numerical models of groundwater, solute fate and transport, bioattenuation, and landfill permitting. Mr. Wickham has considerable experience with low-temperature aqueous geochemistry ranging from simple characterization of water chemistry to development of sophisticated chemical mass balance, aqueous speciation, reaction-path, and reactive fate and transport models using codes such as BALANCE, SOLMINEQ, PHREEQE, PHRQPITZ, and self-authored codes. Mr. Wickham has also designed and conducted tracer studies, identified brine sources using chemical fingerprinting, investigated fate and transport of acidic solutions in neutralizing environments, evaluated impacts from stored acidity, and conducted extensive laboratory testing to characterize water-rock interactions for hazardous waste classification.

Mr. H. Tom Williams, CPESC - Reclamation

Mr. Williams has over 19 years experience in the preparation of reclamation plans, baseline data collection and environmental impact assessments. Mr. Williams has participated in a variety of mining and land development projects. Mr. Williams is a reclamation ecologist and certified erosion control specialist (CPESC #697) with specific expertise in the reclamation and re-vegetation of disturbed lands, wetlands remediation, statistical analysis of vegetation, and erosion and sediment control. Mr. Williams has prepared over 38 reclamation plans for major land disturbance

projects. Mr. Williams has conducted reclamation work for projects in Ireland, Turkey, Russia, Madagascar, Zambia, Canada, Bolivia, Brazil, Suriname, and many states within the U.S. In 1992, Mr. Williams prepared the reclamation plan for a major gold mining project which won the California Mining Association's Award for Excellence and contributed to the clients' receipt of the prestigious Dupont/Conoco Award for Environmental Leadership. In 1995, Mr. Williams prepared a reclamation plan for an abandoned gold mine property in Telluride, Colorado which won the Colorado Division of Mines and Geology's Award for Reclamation Excellence. Currently, Mr. Williams is writing the reclamation plan for the Crown Jewel Mine located in Washington. This reclamation plan is anticipated to be the most extensive hard rock mining reclamation plan yet produced and includes live soil handling, pit sculpting, and the restoration of riparian and high elevation forest communities. In addition to his reclamation work, Mr. Williams has been the project manager and conducted the reclamation and vegetation analyses for over 14 major hard rock mining environmental impact assessments. These assessments were conducted under U.S. National Environmental Policy Act (NEPA), World Bank, European Union (EU), South African and other environmental policies.

The Great River Energy portion of the project will be managed and coordinated by Ms. Diane Stockdill of Coal Creek Station. Ms. Stockdill is currently the Regulatory Services team leader at Coal Creek Station and is responsible for coordinating all of the

environmental programs on the site. Ms. Stockdill has been employed at Coal Creek Station for the past 20 years and has held a variety of positions at the plant.

The Falkirk Mine portion of the project will be managed and coordinated by Mr. Randy Crooke. Mr. Crooke is the Environmental Manager at The Falkirk Mine and is responsible for all aspects of environmental management at the mine, including agency coordination for permitting and reclamation. Mr. Crooke has been employed by The Falkirk Mine for 15 years.

Resumes for all of the key participants in this project are included in Appendix A.

8.0 TIMETABLE

The timetable for the proposed project is as follows:

Activity	Completion Date
Retain Consultants	January, 1999
Geotechnical Work Complete	February, 1999
Geochemical Work Complete	February, 1999
Permit Review	April, 1999
Construction of Cells 1,2 & 3	June, 1999
Equipment Installation	June, 1999
Paste Placement	June through August, 1999
Cold Weather Placement	November & December, 1999
Evaluation of Data	June through December, 1999
Final Report	December 31, 1999

9.0 BUDGET

A budget detailing the costs for the proposed research is included as Table 1 in Appendix B. The total project cost is estimated to be $400,000. GRE has agreed to commit $300,000 of the required funding for the project. The funds being requested from the Industrial Commission of North Dakota are $100,000. An affidavit stating that En-

Rock does not have an outstanding tax liability owed to the state of North Dakota or any of its political subdivisions is also included in Appendix B.

10.0 REFERENCES

1. Bodi, Laszlo, G. Hunt and T. Lahnalampi 1996. "Development and Shear Strength Parameters of Paste Backfill" in *Proceedings of the Third International Conference on Tailings and Mine Waste '96, Fort Collins, Colorado, 16-19 January.* Rotterdam: A. A. Balkema, pp. 169-178.

2. Cincilla. W. A., D. L. Landriault and R. Verburg, 1997. "Application of Paste Technology to Surface Disposal of Mineral Wastes" in *Proceedings of the Fourth International Conference on Tailings and Mine Waste '97, Fort Collins, Colorado, 13-16 January.* Rotterdam: A. A. Balkema, pp. 343-356.

3. Cincilla, W. A. and D. R. East 1989. "The Design and Construction of Fully-Drained Systems for Storage of Mineral Wastes" in *Proceedings of the 21st Mid-Atlantic Industrial Waste Conference, Harrisburg, Pennsylvania, June,* pp. 247-258.

4. Foley, W. E. 1995. "Ash Disposal Systems – Advantages in Technology" *United Nations Development Program, November, 1995.*

5. Knight, R. E. and J. P. Haile 1983. "Sub-Aerial Tailings Deposition" in *Proceedings of the 7th Pan-American Conference on Soil Mechanics and Foundation Engineering, Vancouver, British Columbia, Canada, June 1983.*

6. Landriault, David A. and R. Tenbergen 1995. "The Present State of Paste Fill in Canadian Underground Mining" in *Proceedings of the 97th Annual Meeting of the C.LM. Rock Mechanics and Strata Control Session, Halifax, Nova Scotia, May 14-18, 1995.*

7. Landriault, David A. 1995. "Paste Backfill Mix Design for Canadian Underground Hard Rock Mining" in *Proceedings of the 97th Annual General Meeting of the C.LM. Rock Mechanics and Strata Control Session, Halifax, Nova Scotia, May 14-18, 1995.*

8. Landriault, David A. and W. Lidkea 1993. "Paste Fill and High Density Slurry Fill" in *International Congress on Mine Design, Queens University, Kingston, Ontafio, Canada, August.*

9. Landriault, David A. 1992. "Paste Fill at Inco" in *5th International Symposium on Mining with Backfill,- Johannesburg, South Aftica, September.*

10. Palmer, Bertrand, and R. Krizek 1987. "Thickened Slurry Disposal Method for Process Tailings" *in Geotechnical Practice for Waste Disposal '87, Proceedings of a Specialty Conference sponsored by the Geotechnical Engineering Division of the American Society of Civil Engineers,* edited by Richard D. Woods, New York, ASCE. pp. 728-743.

11. Robertson, A. MacG., J.W. Fischer and Dirk Van Zyl 1982. "Handling and Disposal of Dry Uranium Tailings" in *Proceedings of the 5th Symposium on Uranium Mill Tailings Management, Colorado State University, Fort Collins, Colorado,* pp. 55-69.

12. Robinsky, E. 1979. "Tailings Disposal by the Thickened Discharge Method for Improved Economy and Environmental Control" in *Tailing Disposal Today,* edited by G. Argall. San Francisco: Miller Freeman.

13. Robinsky, E. 1982. "Thickened Tailings Disposal in Any Topography" in *Proceedings of the lllth Annual Meeting A.I. M.E., Metallurgical Society, Dallas, Texas, USA, February, 1982..*

14. Schoenbrunn, F and T. J, Laros 1997. "Dry tailings disposal using high-density thickening" in *Proceedings of the Fourth International Coiiference on Tailings and Mine Waste '97, Fort Collins, Colorado, 13-16January.* Rotterdam: A. A. Balkema, pp. 357-363.

15. Ulrich, B. F. and D. R. East 1996. "Experiences with in situ tests in mine tailings for reclamation and facility expansion" in *Proceedings of the 3rd International Conference on Tailings and Mine Waste '96, Fort Collins, Colorado, 16-19 January.* Rotterdam: A. A. Balkema, pp. 505-513.

16. Verkerk, C. G. and R. Marcus 1988. "The Pumping Characteristics and Rheology of Paste Backfill" in *Backfill in South African Mines.* Johannesburg: SAIMM.

17. Volpe, Richard L. 1978. "Engineering Aspects of the 1972 Buffalo Creek Dam Failure" in *Proceedings of the lst International Symposium on Stability in coal Mining, Vancouver, British Columbia, Canada,* edited by C.O. Brawner. San Francisco: Miller Freeman Publications.

18. Ward, Peter and Thomas Bunn 1996. "The Use of High Density Slurry Technology for Power Station Fly Ash Disposal and Mine Rehabilitation" *Pacific Power International.*

19. Wood, K. R. and G. W. McDonald 1986. "Design and Operation of Thickened Tailings Disposal System at Les Mines Selbaie" *Bulletin of the Canadian Institute of Mining and Metallurgy, November,* pp. 47-53.