MONTANA-DAKOTA
UTILITIES CO.
A Division of MDU Resources Group, Inc.

400 North Fourth Street
Bismarck, ND 58501
(701) 222-7900

October 17, 1996

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
600 East Boulevard Avenue
Bismarck, ND 58505

Subject: Transmittal Letter, North Dakota Lignite Research Program Proposal **'MARKET ASSESSMENT AND DEMONSTRATION OF LIGNITE FBC ASH IN FLOWABLE FILL APPLICATIONS'**

Dear Ms. Fine,

Enclosed please find 35 copies of the proposal, which we are submitting to the North Dakota Industrial Commission for consideration under the Lignite Research Program. This transmittal letter represents a binding commitment by Montana-Dakota Utilities and it's prime contractor Western Research Institute for the completion of the project as described in the proposal. Also enclosed is the $100 application fee.

Part of this project is to determine the marketability of Controlled Density Fill. Preliminary indications, however, are that all of the flyash generated from this station can be marketed within the Bismarck/Mandan area. The R.M. Heskett Station generates approximately 16,000 tons of flyash per year. Marketing a quality approved product such as this, will open the door for non FBC ash in similar products from other North Dakota lignite fired generation facilities.

Sincerely,

Duane O. Steen
DW

Duane O. Steen
Administration and Project Manager

Enclosures

cc: Alan E. Bland - WRI
File

TECHNICAL AND COST PROPOSAL

MARKET ASSESSMENT AND DEMONSTRATION OF LIGNITE FBC ASH IN FLOWABLE FILL APPLICATIONS

Total Funds Requested $37,319

Submitted to:

Lignite Research Program
North Dakota Industrial Commission
State Capital
Bismarck, ND 58508

Submitted by:

Montana Dakota Utilities
Bismarck, ND 58501
and
Western Research Institute
Laramie, WY 82070-3380

Duane O. Steen, Administration & Projects Manager
Corporate Office
Montana Dakota Utilities

Bruce Imsdahl, Vice President
Energy Supply
Montana Dakota Utilities

Dr. Alan E. Bland, Principal Investigator
Office of Engineering
Western Research Institute

Dr. Lee Brecher, Vice President
Office of Engineering
Western Research Institute

October 10, 1996

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

MARKET ASSESSMENT AND DEMONSTRATION OF LIGNITE FBC ASH IN FLOWABLE FILL APPLICATIONS

ABSTRACT

Controlled Low-Strength Flowable Fill Material (CLSFFM) made with ash from the Montana Dakota Utilities (MDU) R. M. Heskett plant appears to be technically viable and environmentally safe. Preliminary testing by Western Research Institute under sponsorship of Montana-Dakota Utilities has been successful in establishing the technical viability of the use of MDU FBC ash in flowable fill applications. However, further testing leading to demonstrations of these materials in a full-scale application is needed for commercialization to progress. The proposal herein provides the marketing, testing, demonstration and follow-up monitoring essential to the commercialization of this material.

Western Research Institute and Montana-Dakota Utilities proposes a 24-month project that will address market assessment and development for the lignite ash flowable fill. The project will include efforts to inform the engineering and environmental communities in the Bismarck-Mandan, North Dakota area of the technical viability, economic advantages, and environmental safety and benefits of this construction material. In addition, laboratory scale testing will be conducted to supplement the preliminary testing effort already conducted by WRI and MDU. This testing will address environmental and geotechnical properties of the flowable fill, as well as the compatibility of the fill with embeds and local North Dakota soils. It is proposed that a full scale demonstration be conducted in the summer of 1997 with a year of geotechnical performance and environmental monitoring by WRI. Upon completion of the project, a new market will be commercially available for the ashes from the burning of lignite in fluidized bed combustors, thereby transforming a present waste product into a salable commodity in the construction industry.

The project will benefit not only MDU, but also the State of North Dakota by potentially establishing the commercial potential of lignite derived ash in flowable fill applications. If successful, the project could lead to additional jobs in the marketing and construction industry as well as demonstrate the environmental benefits of lignite use.

The estimated costs to conduct the marketing and demonstration program as described in the proposal is $152,633. The costs for the program are to be shared by MDU, ND Industrial Commission and WRI through its Cooperative Agreement with the U.S. Department of Energy (METC). MDU will contribute an additional $13,676 in cash above its earlier expenditures of $15,431. MDU will contribute an additional $29,000 of in-kind services and personnel costs associated with the market assessment and demonstration activities, as well as project management. It is requested that the ND Industrial Commission provide $37,319 And finally, WRI and U.S. DOE will match both the MDU and ND Industrial Commission funding for the amount of $72,637. Such cost sharing by WRI will require the approval of the Morgantown Energy Technology Center.

1.0 PROJECT SUMMARY

Controlled Low Strength Flowable Fill Material (CLSFFM) is a construction material that has a number of applications such as removable backfills, structural sills, isolation fills and trench bedding. Conventional flowable fill mixtures consist of water, portland cement, Class 'F' or 'C' fly ash and fine aggregate. CLSFFM has a specified compressive strength ranging from 80 psi to 1200 psi at 28 days, depending upon the application. In addition, CLSFFM have slumps of 9-10 inches, and can be readied for traffic in 2 to 6 hours. This material is not concrete although it is in a flowable state at the time of placement. The CLSFFM is usually mixed in a ready mix concrete truck, keeping the material mixing during transport to prevent segregate of the aggregate. The material can be discharged by either chutes or can be pumped using standard concrete and or grout equipment.

Western Research Institute (WRI) with Montana Dakota Utilities (MDU) sponsorship conducted a preliminary evaluation of the potential of using FBC ash from the MDU R. M. Heskett Station and a local fine aggregate in the formulation of CLSFFM for a number of construction applications. The results of this testing were encouraging and it appeared feasible to produce both 'structural' and 'excavatable' grade CLSFFM composed of small amounts of portland cement with the remainder being FBC ash and local sand aggregate and water. Geotechnical testing indicated that MDU ash based CLSFFM is stable and of sufficient strength for a wide range of applications. The leachate from the MDU FBC fly ash-based CLSFFM meets the regulatory limits for metals as specified by RCRA, thereby resulting in a non-hazardous classification for both the raw fly ash as well as the MDU CLSFFM. The MDU CLSFFM does not appear to be detrimental to embed materials, such as copper, rebar, and portland cement. However, galvanized conduit exposed to the MDU CLSFFM did result in a slight white corrosion scale. It is not clear, based on these relatively short term tests whether this represents a significant problem.

The preliminary testing has not clearly resolved all of the technical issues that must be addressed prior to acceptance by the engineering community or prior to approval by the North Dakota Department of Health. Technical issues such as environmental impact on soils, long-term performance and long term impact on embed materials still exist. Additional tests addressing these issues, as well as demonstration and monitoring of the material in full scale applications are needed before commercialization of this material can be realized.

Based on the results of the preliminary testing, WRI and MDU are proposing a 24-month program of marketing, testing, and demonstration of the MDU ash based CLSFFM for commercial scale applications. The program would be funded by Montana Dakota Utilities, North Dakota Industrial Commission, and the WRI-U.S. DOE Jointly Sponsored Research Program. The program will address:

(1) MDU CLSFFM Market Assessment designed at convincing both the engineering community and the North Dakota Department of Health of the benefits and inherent environmental safety of the MDU ash-based CLSFFM. MDU and WRI personnel will engage workshops; meeting and discussions with the City of Engineering Departments; contractors, and discussions with the ND Department of Health. The objectives of these activities are to inform these parties about the engineering and environmental properties of the MDU CLSSFM; (2) ascertain their concerns so that they can be addressed through further testing; and (3) ultimately receive their endorsement or permission to pursue full scale demonstration of the MDU CLSFFM.

(2) Additional CLSFFM Geotechnical Testing -Although the results of the preliminary testing appear to be promising, there are a number of issues that need further clarification, including (1) better definition of the pressures of expansion-shrinkage associated with wet-dry cycling; (2) better definition of the settlement characteristics of the CLSFFM; (3) determination of the benefit of air entraining agents (AEA) on freeze/thaw durability; (4) assessment of the permeability and permeate quality of CLSFFM and interaction with local soils; and (5) assessment of longer term embed materials compatibility (particularly with galvanized conduit) with MDU CLSFFM. These items will be addressed prior to any commercial application of the MDU CLSFFM.

(3) Demonstration of MDU CLSFFM in North Dakota - Discussions with MDU personnel have indicated that they believe that there are a number of demonstration opportunities in the Bismarck-Mandan area for the CLSFFM. MDU and WRI will pursue these opportunities and a demonstration of the application of MDU CLSFFM will be conducted in the Bismarck-Mandan area during the summer of 1997. Two demonstrations are proposed addressing the structural grade CLSFFM as well as the excavatable (trench filling) CLSFFM applications. These demonstrations will verify the potential of the MDU CLSFFM using full-scale equipment. The size of the demonstrations will be sufficient to allow the assessment of the economic benefits of flowable fills to be ascertained, as well as the environmental characteristics and the technical performance of the MDU CLSFFM.

(4) Monitoring of MDU CLSFFM Demonstration - WRI will provide technical monitoring support for the demonstration activities. This support is in the form of geotechnical and environmental monitoring. The geotechnical properties, such as strength, flow, set characteristics and dimensional stability will be monitored for each demonstration. Environmental leachate analyses will be conducted on both of the CLSFFM materials used in the demonstrations. Additional monitoring requirements may result from discussions with the ND Department of Health and other regulatory and engineering entities.

The project, if successful, is expected to establish a new market for lignite based ash in the construction industry. This will have a positive advantage to the lignite industry, specifically the users of North Dakota lignite. The successful commercial development of markets for the ash is of an environmental benefit as well as an economic benefit to the lignite user. The creation of jobs would be another direct benefit to the local and State economy.

2.0 PROJECT DESCRIPTION

Controlled Low Strength Flowable Fill Material (CLSFFM) is a construction material that has gained acceptance for a number of construction applications. The performance characteristics can be modified for the specific application. CLSFFM allows for reduced excavation costs and the performance characteristics can be modified for the specific construction application. CLSFFM has been shown to be competitive with other construction methods. The applications for CLSFFM have been documented in the literature and CLSFFM is considered a commercial product in most regions of the country. Applications such as removable backfills, structural sills, isolation fills and trench bedding have been demonstrated.

Recent mix designs for CLSFFM have focused on the use of alternate materials such as fly ash and waste aggregate materials in an effort to reduce costs. Typical flowable fill mixtures consist of water, portland cement, Class 'F' or 'C' fly ash and fine aggregate. Ash from MDU's Heskett Station in Mandan, North Dakota represents one such alternative material.. The potential use of the ash from this fluidized bed combustor (FBC) in the formulation of a flowable fill for a variety of construction applications in the Bismarck area was an option worth pursuing by MDU.

Western Research Institute (WRI) with sponsorship from Montana Dakota Utilities (MDU) performed a preliminary evaluation of the potential of using FBC ash from the Montana Dakota utilities R. M. Heskett Station and a local fine aggregate in the formulation of CLSFFM for a number of construction applications. The results of the testing were encouraging and it appeared that both 'structural' and 'excavatable' grade CLSFFM can be formulated that uses between 6.2 % and 2.6 % Type I/II portland cement and 10 % to 14 % FBC fly ash, with the remainder being local sand aggregate and water. The geotechnical testing also indicated that MDU ash based CLSFFM is stable and of sufficient strength for a wide range of applications. The leachate from the MDU FBC fly ash-based CLSFFM meets the regulatory limits for metals as specified by RCRA thereby resulting in a non-hazardous classification for both the raw fly ash as well as the MDU CLSFFM. The MDU CLSFFM does not appear to be detrimental to embed materials, such as copper, rebar, and portland cement. However, galvanized conduit exposed to the MDU CLSFFM did result in a slight white corrosion scale. It is not clear, based on these relatively short term tests whether this represents a significant problem.

Preliminary testing has not clearly delineated all of the technical issues that must be addressed prior to acceptance by the engineering community and prior to approval by the North Dakota Department of Health. Additional testing, as well as demonstration and monitoring of the material in full scale applications are needed based on the results of the preliminary testing. WRI and MDU are proposing a program of marketing, testing, and demonstration of the MDU CLSFFM in commercial scale applications. This Marketing and Demonstration program incorporates the following tasks.

Task I.	MDU CLSFFM Market Assessment
Task II.	MDU CLSFFM Additional Testing
Task III.	Demonstration of MDU CLSFFM in North Dakota
Task IV.	Monitoring of MDU CLSFFM Demonstrations
Task V.	Reporting

The following represent a brief description of each of these tasks.

2.1 Task I. MDU CLSFFM Market Assessment - The MDU CLSFFM appears to be a viable engineering material capable of effecting cost savings for a number of construction applications. However, the engineering and construction industry must be convinced prior to their use or specification of the material. Testing has also shown the material to be non-hazardous according to U. S. EPA Toxicity Characteristics Leaching Procedure (TCLP) testing. However, the environmental regulatory agencies must be convinced of the safety and environmental benefits of the material. Market assessments and marketing of the MDU CLSFFM are integral to convincing both the engineering community and the North Dakota Department of Health of the benefits and inherent environmental safety of the MDU CLSFFM in construction applications in North Dakota.

Although the TCLP extracts do appear to meet the Drinking Water Standards for the RCRA metals, the North Dakota Department of Health (NDDH) has continuing concerns with the levels of sulfates, chlorides, and radionuclides. NDDH believes that alternate leaching procedures other than TCLP may be more appropriate in assessing the impact on water resources and the impact on local soils. These concerns are addressed in our proposed permeability and permeate testing as part of Task II.

As part of the market assessment, MDU and WRI personnel will participate in workshops; meetings and discussions with various engineering departments and contractors, and the ND Department of Health. The objectives of these activities are to inform these parties about the engineering and environmental properties of the MDU CLSSFM; (2) ascertain their concerns so that they can be addressed through further testing; and (3) ultimately receive their endorsement or permission to pursue a demonstration of the MDU CLSFFM.

2.2 Task II. MDU CLSFFM Additional Testing -

Although the results of the preliminary testing appear to be promising, there are a number of technical issues that need further clarification relating to geotechnical and environmental performance. The geotechnical properties that remain undefined include: (1) better definition of the pressures of expansion-shrinkage associated with wet-dry cycling; (2) better definition of the settlement characteristics of the CLSFFM; (3) determination of the benefit of AEA on freeze/thaw durability; (4) assessment of the permeability and permeate quality of CLSFFM and its impact on soils; and (5) assessment of longer term embed materials compatibility (particularly with galvanized conduit) with MDU CLSFFM.

Expansion-Shrinkage Pressures - Wet/dry cycle durability testing by WRI of the MDU CLSFFM indicated that there was a expansion-shrinkage cycling of the material coincident with the wet/dry cycles. Although small in magnitude, this swelling and contraction of the material on wet/dry cycling could be detrimental to embed materials. However, the testing was conducted under zero load pressures. It is unclear whether under loads equivalent of several feet of fill material if the expansion/shrinkage would still exist. As a result, testing will be conducted to determine the pressures exerted by the CLSFFM during wet/dry cycles. ASTM D-2435 and 3877 will be modified to determine these values. In these tests, the load is changed to present a non-expanding situation. The pressure associated with this load represents the amount of load (depth of fill) necessary to stop the expansion/shrinkage.

Settlement - The testing by WRI has shown that the MDU CLSFFM meets the requirements related to settlement for excavatable trench applications. However, WRI has yet to substantiate the settlement characteristics of structural fill applications. The settlement issue is of concern for structural fill applications in that these fill materials must support substantial loads. ASTM

D2435 will be employed to assess the settlement characteristics of the MDU structural grade CLSFFM>

Freeze/Thaw Cycle Performance - Preliminary testing by WRI confirmed that commercially available air-entraining agents (AEA) are compatible with MDU CLSFFM, in that they do entrain air. The entrained air is important in developing a resistance to deterioration when the material is subjected to freeze/thaw conditions. Freeze/thaw durability is important for structural-grade CLSFFM applications more so than for the excavatable trench grade CLSFFM applications. The benefit of AEA dosages on the freeze/thaw cycle resistance of the structural grade CLSFFM will be quantified according to ASTM D-560 testing.

Permeate Characteristics - North Dakota Department of Health has expressed concern that the TCLP procedure does not provide a realistic assessment of the leachate characteristics of the CLSFFM. This position has been expressed by many in the field. Instead, they recommended the use of the ASTM shake extraction procedure that employs distilled water in a shake test. It is unclear if this procedure is more reflective of actual field conditions. In addition to the required ASTM test, WRI is proposing to use tests to evaluate the impact of the exposed surfaces of the CLSFFM on the leachate quality as one would expect under field conditions. The permeate from these tests would be used as a basis for assessing the leachate characteristics of the CLSFFM. The impact of the leachate on the local soils can also be assess in a similar set of tests, wherein the permeate from the CLSFFM is used to assess the impact on North Dakota soils.

Embed Compatibility - The presence of elevated concentrations of sulfate and chlorides in the leachate from CLSFFM was a concern due its potential to cause corrosion of embeds that could be placed in the CLSFFM. WRI developed a method of assessing this potential corrosion and employed it on the MDU CLSFFM. The method involves the embedding of coupons of various materials of construction (portland cement, rebar, conduit etc.) in the CLSFFM and then subjecting the CLSFFM to wet/dry cycles for specified periods. These conditions are considered to accelerate the corrosion potential and as such provide worst case results. The preliminary WRI testing was short in duration (up to three months), and therefore propose to continue this testing for longer duration (up to 1 year).

In addition to these tests, it is expected that the discussions as part of the market assessment efforts are expected to result in the requirement for additional testing to answer the concerns of the engineering community and the ND Department of Health. These concerns will also be addressed as part of the testing effort.

2.3 Task III. Demonstration of MDU CLSFFM in North Dakota - There are a number of demonstration opportunities in the Bismarck-Mandan area, wherein the performance of the MDU CLSFFM could be demonstrated. MDU personnel will pursue these opportunities and specific construction demonstrations of the MDU CLSFFM will be conducted in the Bismarck-Mandan area during the summer of 1997.

Two demonstrations are proposed addressing the structural grade CLSFFM as well as the excavatable (trench filling) CLSFFM applications. It is proposed that commercially available CLSFFM also be emplaced in adjacent trenches for comparison. Commercially available flowable fill will not be used for comparison purposes for the structural fill, due to the relatively large costs associated with this demonstration. These demonstrations will verify the potential of the MDU CLSFFM using full-scale equipment. The size of the demonstrations will be sufficient to assess the economic benefits of MDU flowable fills, as well as the technical performance of the MDU CLSFFM.

At the time of the demonstrations, samples of each of the CLSFFM will be taken and test specimens fabricated to evaluate strength development, flow characteristics, set characteristics, and dimensional stability. These samples will be tested as part of the monitoring activities of Task IV. For the structural fill demonstration the placement and surveying of pins in the CLSFFM may also be conducted. These pins allow for an assessment of any swelling/settlement or lateral expansion. For both the excavatable trench filling demonstration and the structural fill demonstration, lysimeters will be emplaced in the CLSFFM at the time of construction and used during the monitoring activities to extract leachate samples. There are no plans to monitor groundwater via monitoring wells, due to the high costs of such activities and since the impact of CLSFFM on ground water is expected to be minimal.

2.4 Task IV. Monitoring of MDU CLSFFM Demonstration - WRI proposes to provide technical monitoring support for the two demonstration activities. This support is in the form of both geotechnical and environmental monitoring. Both of the demonstrations will be monitored over a 1 year period for strength development, settlement and dimensional stability. The demonstration sites will be visited, visual performance recorded, solid samples extracted and tested for strength and other geotechincal properties, as well as such as chemical properties, such as leachate (pore water) extracts. The phase chemistry of the retrieved sampled will also be determined in order to assess the chemical changes that are occurring during aging. Water samples will be collected from the lysimeters, if possible, and correlated with the laboratory data. Additional tests may result from discussions with the ND Department of Health and other regulatory and engineering entities. The results of this monitoring effort are designed to verify the engineering value and environmentally benign character of the MDU CLSFFM.

2.5 Task V. Reporting - Quarterly reporting of the progress of the project will be implemented. An Interim Report will be prepared for MDU, ND Lignite Research Council and U.S. DOE in August, 1997 covering the laboratory testing activities and a brief Interim report will be prepared in October, 1997 covering the emplacement of the demonstrations. A Final Report will be prepared for both MDU, ND Lignite Research Council and U.S. DOE in December, 1997 that will include the monitoring activities.

3.0 STANDARDS OF SUCCESS

The following milestones will be used to measure the success of the project. These milestones are incorporated in the Timetable for the project.

> ***Milestone 1. Contract Awards*** by ND Industrial Commission and USDOE. Must be under contract with all potential funding sponsors (MDU, NDIC, and USDOE) by end of December. 1996

Milestone 2. ***Conduct Additional Testing Program*** - Finish by July 1997. Interim Report on Testing Program will be provided. Testing must result in ND Department of Health approval and with the support from engineering community to warrant a demonstration.

Milestone 3. ***Identify and Receive Commitment for Demonstration*** no later than end of July, 1997.

Milestone 5. ***Establish the Monitoring Requirements*** for the demonstration no later than end of July, 1997.

Milestone 5. ***Conduct Full Scale Demonstration*** in North Dakota with the approval of ND Department of Health and support of the engineering agency. by no later than end of August, 1997

Milestone 6. ***Deliver Final Report*** on Project to funding sponsors by November 30, 1998 Final report with comments from cosponsors by end of December, 1998.

Progress on the project will be reported through brief quarterly reports. These reports will be submitted to North Dakota Industrial Commission by MDU based on the reports by Western Research Institute. Reports to the U..S.. Department of Energy after review by MDU personnel will be submitted by WRI. The first quarterly report will be made to coincide with the USDOE reporting schedule in order to minimize the reporting requirements Teleconference calls and other progress reporting between MDU personnel, Western Research Institute, and ND Industrial Commission will take place as the need arises. The first quarterly report will be delivered on or before the 10^{th} of the month on a quarterly basis, starting January, 1997. The first report will describe the status of all of the cosponsor proposals and approved scope of work. The Interim reports covering the results of the laboratory testing program (July, 1997), demonstrations (October, 1997) will be delivered as dated and a Draft final report on the project delivered November 30, 1998 with the corrected version due December, 1998.

4.0 BACKGROUND

Montana Dakota Utilities (MDU) is a generator of power for a major part of the northern Rocky Mountain area, and as such ashes generated from MDU facilities must be disposed or used in beneficial applications. Ash from MDU's R. M. Heskett Station in Mandan, North Dakota represents one such ash management challenge. One potential use of the ash from this fluidized bed combustor (FBC) is in the formulation of a flowable fill for a variety of construction applications in the Bismarck area.

4.1 Flowable Fills and Applications - Conventional CLSFFM mixtures consist of water, portland cement, Class 'F' or 'C' fly ash and fine aggregate. CLSFFM is a construction material that has a specified compressive strength ranging from 80 psi to 1200 psi at 28 days, depending on the application. The characteristics of the CLSFFM also include a high slump of 9-10 inches and can be readied for use in 2 to 6 hours. This material is not concrete and is in a flowable state at the time of placement. The CLSFFM is usually mixed in a ready mix concrete truck, keeping the material mixing during transport to prevent segregate of the aggregate. The material can be discharged by either chutes or can be pumped using standard concrete and or grout equipment.

A number of applications for CLSFFM have been documented in the literature (see Relevant References section 12.0). Conventional CLSFFM is considered a commercial product in most regions of the country. A major consideration in the use of CLSFFM is the relative economics with other construction materials and methods. CLSFFM has been shown to be competitive with these other construction methods. A number of these applications include:

- removable backfills
- structural fills
- isolation fills
- trench bedding
- road base
- floor base
- void fills
- caisson and pile fills and
- small bridge restorations.

Table 1.
Typical Mix Proportions and Characteristics of Conventional Controlled Low Strength Flowable Fill Materials.

Construction Application	*Cement (1)*	*Type F Fly Ash (1)*	*Fine Sand Aggregate (1)*	*Water (1)*	*28 day UCS (psi)*
Backfill	50	250-300	2700-2800	400-500	80
Structural	200	250-300	2800	380	1000
Floor	100	250-300	3100	300	500
Backfill (No fly ash)	100	9 oz AEA(2)	2800-2900	500	80

(1) lbs/cu. yd.
(2) ounces/cu. yd.

Backfills - Granular or site excavated backfills, even if compacted properly in the required thickness layers may not achieve the uniformity of CLSFFM. CLSFFM has been used as a backfill around structures, buried tanks and various conduit materials, such as concrete, metal, fiberglass, reinforced plastic and vitrified clay. The compressive strength of CLSFFM backfill is usually 80 psi or less.

Structural Fill - CLSFFM may be used for foundation support, in that it helps to distribute the structure's load over weak soil. In the case of uneven soil surfaces the CLSFFM provides a uniform surface for foundation structure. Structural fill mixtures typically have compressive strengths in the range of 200 to 1,000 psi.

Isolation Fills - CLSFFM mixtures may provide good density and strength characteristics that may reduce the transfer of vibration and shock.

Road Base - CLSFFM mixtures have been used for pavement bases and subbases in subdivision, arterial streets and parking lots. The mixtures can be placed directly from mixer onto the subgrade between curbs. According to AASHTO, the structural coefficients for this type of material are in the range of 0.25 and 0.35 depending upon the compressive strength that is achieved in the field. CLSFFM must have a wearing surface applied since they typically have poor wear resistance.

Trench Bedding - CLSFFM mixtures can be placed around and under conduit as trench bedding to provide uniform support and uniform density. Strengths are maintained low in order to facilitate excavation if needed.

Void Filling - Cavities under slabs, pavement and structures have been filled with CLSFFM. For these applications erosion conditions should be considered. Abandoned mines, old sewers, and underground tanks have been filled with CLSFFM.

Non-standard materials in the formulation of CLSFFM have been used and their selection is typically based on the flowability, strength, removability, and density characteristics of the resultant mix.

4.2 Results of Preliminary Testing Program - Western Research Institute (WRI) under sponsorship by Montana Dakota Utilities conducted a preliminary evaluation of the potential of using FBC ash from the Montana Dakota Utilities R. M. Heskett Station and a local fine aggregate in the formulation of CLSFFM for a number of construction applications. In order for MDU FBC fly ash-based CLSFFM to be a viable material for construction applications, MDU recommended that it must meet a number of targeted performance specifications, including (1) flowable (8-inch flow), (2) achieve initial set of at least 27 psi within 4 hours, (3) possess strengths less than 150 psi to allow for re-excavation, (4) have non-shrink or settlement characteristics, (5) exhibit benign environmental leachate characteristics, and (6) be compatible with embedded materials, such as pipe and conduit. The results of the testing are encouraging and it does appear feasible to produce a CLSFFM that meets the geotechnical and environmental specifications as set forth above. Specifically the testing has concluded the following:

- Both 'structural' and 'excavatable' grade CLSFFM can be fabricated that uses between 6.2 % and 2.6 % Type I/II portland cement and 10 % to 14 % FBC fly ash, with the remainder being local sand aggregate and water. The use of sulfate resistant cements (e.g., Type III and Type V) do not appear to be warranted.

- The MDU FBC fly ash-based CLSFFM meet the geotechnical specifications commonly found for conventional CLSFFM, including flows of 8-inches or more, set times for achieving 27 psi in the range of 4 to 5 hours, ultimate strengths of less than 150 psi for 'excavatable' CLSFFM and greater than 200 psi for 'structural' grade CLSFFM (see Table 2). Expansion characteristics of the CLSFFM appear to indicate a dimensionally stable material. However, under wet-dry cycling, there was an observed expansion-shrinkage cycling of the order of 0.05% that matched the wet and dry cycling. It is unclear if sufficient pressures are present to create stresses to the embedded materials.

Table 2.
Summary of Performance of 'Structural' and 'Excavatable' Grade CLSFFM

	MDU Excavatable Grade Flowable Fill	*MDU Structural Grade Flowable Fill*
Mix Proportions		
MDU FBC Fly Ash (lbs/cu. yd.)	353	356
Portland Cement (lbs/cu. yd.)	63	150
Aggregate Wash Fines (lbs/cu. yd.)	2116	2135
Water (gal./cu. yd.)	67.7 gal.	75.0 gal.
Darafill (oz/cu. yd.)	2 oz.	2 oz.
Chloride Accelerator (%)	1%	1%
Mix Properties		
Yield (lbs/cu. yd.)	2997	3159
Flow (inch)	8-inch minimum	8-inch minimum
Time to Traffic (hrs)	4-5 hrs	4-5 hrs
UCS @ 28 days (psi)	70 psi	>200 psi
Expansion under Sealed and W/D Cycles (%)	0.004-0.113%	0.004-0.113%

- The use of FBC fly ash did retard the strength development, thereby requiring the addition of commercially available accelerators. Calcium chloride based accelerators appear to be best suited for these applications.

- The desire to improve freeze/thaw durability for North Dakota applications necessitated the need for low dosages of a commercially available air entraining agent (AEA). Darafill by WR Grace Construction Products appears to be an effective AEA for these CLSFFM.

- The MDU CLSFFM does not appear to be detrimental to embed materials, such as copper, rebar, and portland cement. However, galvanized conduit exposed to the MDU CLSFFM did result in a slight white corrosion scale. It is not clear, based on the results of the testing if this represents a significant problem.

- The leachate from the MDU FBC fly ash-based CLSFFM meets the regulatory limits for metals as specified by RCRA thereby resulting in a non-hazardous classification for both the raw fly ash, as well as the MDU CLSFFM. In fact, the TCLP leachate meets many of the Drinking Water Standards.

Table 3.
Summary of TCLP Leachate Composition of the MDU Fly Ash and MDU and Conventional CLSFFM.

	RCRA Limits	*MDU Fly Ash - 5/94*	*MDU Fly Ash - 6/87*	*MDU CLSFFM*	*MDU CLSFFM*
CLSFFM Grade				*'S'*	*'E'*
Arsenic	5.0	<0.10	<0.5	0.006	0.016
Barium	100.0	0.768	<10	0.753	0.444
Cadmium	1.0	<0.010	<0.1	<0.010	<0.010
Chromium	5.0	<0.008	<0.5	0.021	<0.008
Lead	5.0	<0.200	<0.5	<0.100	<0.100
Mercury	0.02	<0.002	<0.02	<0.002	<0.002
Selenium	1.0	<0.100	<0.2	<0.200	<0.200
Silver	5.0	<0.010	<0.5	<0.010	<0.010
pH	<12.5	11.8	nd	11.0	9.9
Chlorides	na	nd	nd	231	258
Sulfates	na	nd	nd	394	586

'S' - Structural
'E' - Excavatable

5.0 VALUE TO NORTH DAKOTA

The project will benefit not only MDU, but also the State of North Dakota by establishing the commercial potential of lignite derived FBC ash in flowable fill applications. The project, if successful, is expected to clearly establish a new market for lignite based ash in the construction industry. This will have a positive advantage to the lignite industry, specifically the users of North Dakota lignite. The successful commercial development of markets for the ash is of an environmental benefit as well as an economic benefit to the lignite user. The creation of jobs would be another direct benefit to the local and State economy.

6.0 QUALIFICATIONS

A team of researchers from Western Research Institute (WRI) has been assembled that bring together the combination of science, engineering and commercialization necessary to successfully perform the scope of the project as outlined above. WRI is a nonprofit research and development organization. Western Research Institute maintains a 52,000-square-feet laboratory facility on 2.3 acres located adjacent to the University of Wyoming (UW) campus in Laramie, Wyoming. Four satellite buildings (5,000 square feet) house specialized research and development laboratories and sample preparation equipment. In addition to the main facility, WRI operates a 22-acre Advanced Technology Center (ATC) site on the north edge of Laramie. The ATC facilities include a 22,000-square-feet combustion and in-situ remediation laboratory, a 5,400 square-feet 0.5 MW gas turbine pilot facility, a 3,000 square-feet pilot-scale electric down-hole steam generator for enhanced petroleum recovery, and a 7,000-square-feet waste management laboratory complex. The ATC also houses seven other pilot plants, and complete fabrication and maintenance shops. WRI's 92 employees provide professional, technical and administrative support to all WRI operations.

The main facility is equipped with over $22 million worth of instruments to perform a full range of ASTM and specialized analytical and laboratory testing work. This equipment includes computerized gas chromatographs/mass spectrometers (GC/MS), inductively coupled plasma (ICP) spectrometer, atomic absorption (AA), infrared (IR) spectrometer, high performance liquid chromatograph (HPLC), solids NMR spectrometer, X-ray powder diffraction (XRD), thermogravimetric analysis (TGA), differential thermogravimetric analysis (DTA), differential scanning calorimetry (DSC) and scanning electron microscope (SEM). A HIAC PA720 is available for determining the particle size distribution of the waste materials. WRI has a complete facility for the extraction of leachates from wastes under a range of protocols, including EP, TCLP, and CalWET.

WRI has complete facilities for the evaluation of a range of solid waste and wastewater treatment processes. Water and wastewater treatment/remediation equipment includes filtration, bioremediation, containment, pump and treat technologies, froth flotation, steam stripping, ion exchange, carbon adsorption, reverse osmosis, chemical coagulation and flocculation, and electro-coagulation. Sludge treatment processes include extraction of hydrocarbons from tank bottoms (TaBoRR process), thermal oxidation, wet-air oxidation, soil washing, including steam and hot water flushing and surfactant washing. A range of combustion, pyrolysis, and incineration processes are also available, such as starved air incineration, fluidized bed combustion, and vortex incineration of gaseous pollutants.

The Waste Management Laboratory is located at the Advanced Technology Center and houses a variety of laboratory and pilot-scale waste treatment and testing equipment. The facility was designed to evaluate various waste management options including stabilization, contaminant removal (soil washing), and solid waste use. WRI has fully equipped facility capable of performing all of the related ASTM and AASHTO tests. A summary of the types of equipment is presented in Appendix B and C. In addition to these facilities, WRI has access to specialized resilient and dynamic modulus and modulus of rupture and elasticity testing facilities at the UW Department of Civil Engineering and the Wyoming Department of Transportation.

Western Research Institute personnel have been involved in the development of technologies and management practices for the disposal/utilization of solid wastes for nearly two decades. The experience includes the solid wastes from shale production and processing, conventional Class C and F fly ashes, and advanced coal combustion/desulfurization technology ashes. The team as assembled for the project has a long history of activity in the area of ash handling, disposal, and utilization. WRI personnel have been involved in the development of ash management options for advanced coal combustion/desulfurization ashes for over the last decade. Their experience with conventional and advanced coal combustion/desulfurization technology ashes is well documented. A summary of WRI personnel experience and selected key projects is presented in Appendix C.

Key Personnel

Mr. Duane O. Steen of Montana Dakota Utilities will manage the project. Western Research Institute will conduct the testing as outlined herein under the direction of Dr. Alan E. Bland, who will serve as Principal Investigator. Dr. Terry H. Brown, Dr. Vijay K. Sethi and Susan Sorini will assist in directing key components of the testing program. A brief description of the key personnel and their project responsibilities is provided below.

Duane O. Steen, B.S. Mechanical Engineering - Mr Steen has been Administration and Projects Manager in the Corporate Office of Montana Dakota Utilities since 1992. The responsibilities of the position are to oversee the accounting end of Montana Dakota Utilities' power plants as well as to manage various projects. Currently working on projects for utilization of coal ash, analysis of in-house and outside investment in future generation projects, and a number of economic development projects. Since joining Montana Dakota Utilities in 1974. Mr. Steen has been Results Engineer and Results Supervisor at the Lewis and Clark Station, a 50 MW lignite-fired power plant. Steen has also been Operations Coordinator in the Power Production Department at Corporate headquarters, and. Station Superintendent and Manager at both the Lewis and Clark Station and the R. M. Heskett Station. As Station Manager, he was responsible for the overall operation of these two coal-fired generating units. The R. M. Heskett Station is a two unit lignite-fired plant consisting of a 20 MW unit and a 66 MW unit. As Station Manager at the R. M. Heskett Station, Steen was directly involved with the conversion of the 66 MW stoker fired unit to an 80 MW fluidized bed combustion unit. His responsibilities included initial design review, on-site construction supervision, start-up and operation. Duane Steen is a professional engineer in the State of North Dakota and has over 22 years experience in the power generation industry, including lignite coal-fired fluidized bed combustion. Mr. Steen has numerous years of project management and is well versed in the area of coal ash management.

Dr. Alan E. Bland, PhD. - Dr. Bland joined WRI in August of 1991, where he is part of the Senior Research Staff, responsible for solid waste research and development activities. Dr. Bland has over 15 years of experience with ash management issues for advanced coal combustion/desulfurization technology ashes. Current ash management projects include synthetic aggregate production from ash, the production of ash based flowable fills, PFA ash use in soil stabilization and cement treated base applications for DOE and PacifiCorp; CFBC ash pelletizing studies for a number of industrial and cogeneration clients; and incinerator ash studies for confidential industrial clients. Dr. Bland is Project Manager for the U.S. DOE sponsored development of SYN-AG™, a synthetic aggregate for contruction applications, In addition, Dr. Bland is the Project Manager for the evaluation of market potential and use options for pressurized fluidized bed combustion ashes, co-sponsored by U.S. DOE, EPRI and Foster Wheeler International. Dr. Bland has authored or co-authored over 50 publications, many of which have been presented at national and international conferences. Dr. Bland serves on the steering committee of the International Conference on Fluidized Bed Combustion and is Topic Chairman of the Environmental Issues for that Conference. Dr. Bland is a member of SME/AIME and the American Chemical Society.

Dr. Bland will be responsible for the overall project testing by WRI and will provide the point of reporting to MDU and thereby to NDIC.

Dr. Terry H. Brown, Ph.D. Dr. Brown is a Senior Research Scientist, Environmental Technology at the Western Research Institute, responsible for research and development programs in the area of waste remediation, soil washing, waste stabilization and disposal, and solution chemistry aspects of waste management. Dr. Brown has been the Project Manager on projects involving the physical and chemical treatment of hazardous waste contaminated soils as part of a development program for a soil washing technology termed Haz-Flote™, which is capable of treating both organic and inorganic contaminated soils. Dr. Brown is presently the Project Manager for a project with Public Service of Colorado that addresses the disposal and liner compatibility of a number of CCT ashes from the Arapahoe No. 4 Clean Coal Technology demonstration project. Dr. Brown is currently involved in the solution chemistry and phase reaction chemistry for both conventional and FBC ashes. Dr. Brown worked on the preliminary testing of flowable fill materials from FBC ashes.

Dr. Brown has authored numerous papers and reports associated with ash and waste management, many of which have been presented to national and international conferences.

Dr. Brown will be involved in the conduct, and interpretation of permeability and soils compatibility testing under Task II, as well as involved in the demonstration (Task III) and the monitoring activities (Task IV). Dr. Brown will report through Dr. A. E. Bland for this work.

Dr. Vijay K. Sethi, PhD At Western Research Institute, Dr. Sethi is responsible for projects dealing with corrosion, erosion-corrosion, and other materials degradation problems in advanced coal and biomass utilization technologies. He is also responsible for process development and optimization for advanced coal drying, coal gasification, and higher efficiency coal combustion systems. He is also working with the WRI Oil and Gas group to develop and test technologies for surface processing of oil sands, tank-bottom recovery, and projects involving remediation of oil/hydrocarbon contaminated soils. Dr. Sethi is working with the Tennessee Valley Authority in testing materials at the 160 MWe atmospheric fluidized bed coal combustor located at the TVA Shawnee Steam Plant. Dr Sethi designed and supervised the preliminary embed compatibility testing of MDU ash based flowable fill.

Dr. Sethi has over a hundred publications, and nearly that many presentations. He is a member of various trade societies including ASM International, National Association of Corrosion Engineers, AIME.

Dr. Sethi will be responsible for the design and interpretation of the materials compatibility tests to be conducted under TaskII. Dr. Sethi will report through Dr. A. E. Bland for this work.

Susan S. Sorini, BS. S. Sorini is currently Principal Research Scientist in the Environmental Technology Group at Western Research Institute, where she is responsible for waste characterization and methods development and validation. Ms. Sorini is currently the Project Manager of a project to develop and validate a sequential batch extraction method using dilute acid solution simulating acid rain as the extraction fluid. Ms. Sorini is also currently involved in a hazardous waste clean-up program for U.S. DOE. The site has been contaminated with both inorganic heavy metals and organic contaminants. Ms. Sorini was Task Leader for the U.S. Environmental Protection Agency (EPA) involved in the development and evaluation of Toxicity Characteristic Leaching Procedure (TCLP) and the Liquid Release Test (LRT). Ms. Sorini has managed projects for the preparation of TCLP reference samples and evaluation of regulatory testing equipment and has conducted projects for the Electric Power Research Institute (EPRI) and the Utility Solid Waste Activities Group (USWAG). Ms Sorini is presently preparing a summary paper on ash leaching methods for the American Coal Ash Association.

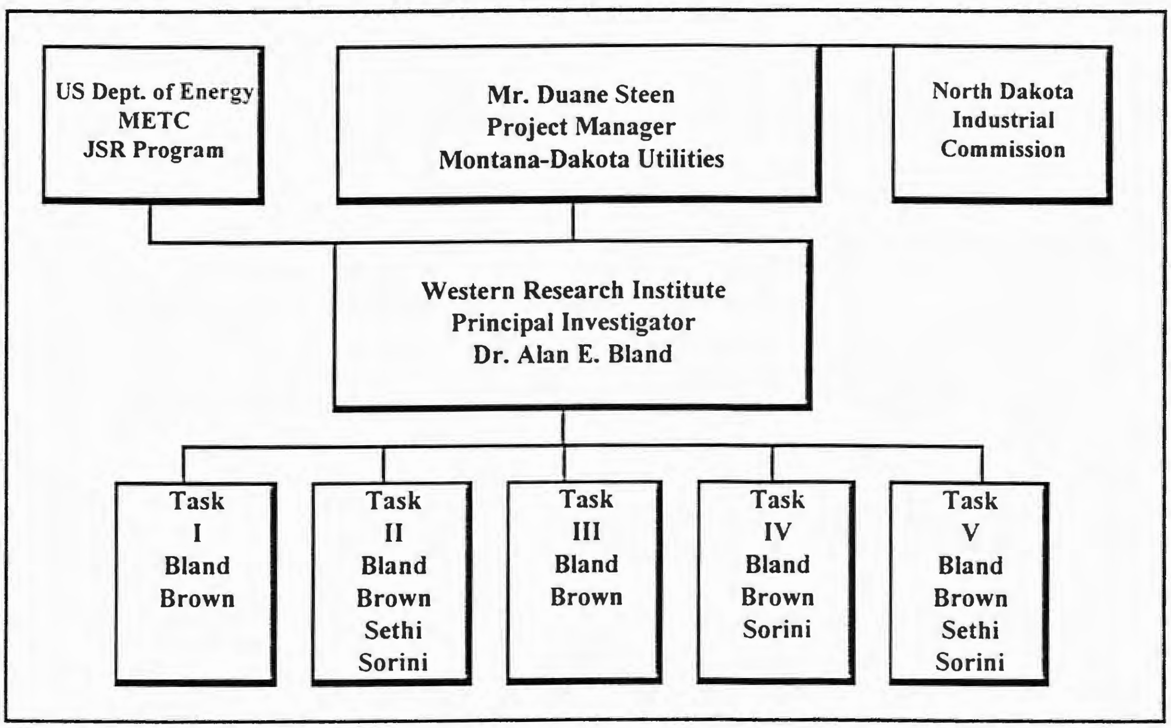
Ms. Sorini serves as the Chairperson for the ASTM Task Group D34.02,01 on Waste Leaching Techniques and author of the ASTM Method D4793, Standard Test Method for Sequential Batch Extraction of Waste and Water. Ms. Sorini has authored or coauthored 12 publications dealing with solid waste characterization and testing methods.

Ms. Sorini will be responsible for the leaching protocol and permeate analyses under Task II. She will report through Dr. A. E. Bland for this work.

7.0 PROJECT MANAGEMENT

Mr. Duane Steen of Montana-Dakota Utilities will serve as the Project Manager, reporting to North Dakota Industrial Commission. Western Research Institute will conduct the testing as outlined herein under the direction of Dr. Alan E. Bland, who will serve as Principal Investigator. The project organizational chart is presented in Figure 1.

Figure 1.
Project Organizational Chart



Key WRI personnel include Dr. Alan E. Bland, Dr. Terry H. Brown, Dr. Vijay K. Sethi, and Susan Sorini. All reports, including Interim Testing Report, Interim Demonstration Report, as well as Final report will be prepared by Dr. Bland with contribution from these key WRI personnel.

Project reporting to the North Dakota Industrial Commission will be via Mr. Duane O. Steen as shown in Figure 1. Dr. Bland of WRI will work directly with Mr. Steen of MDU related to the project. Mr. Steen will be an integral part of the marketing and demonstration activities, as well as project Manager reporting to NDIC. U.S. Department of Energy reporting will be through WRI's Jointly Sponsored Research Program administered through Dr. Lee E. Brecher of WRI.

8.0 TIMETABLE

It is anticipated that the project will take approximately 24 months to complete with the following milestones.

December, 1996	Contracts Awarded
December through March, 1997	Conduct Market Assessments
December, 1996 through July 1997	Conduct Additional Testing Program
July 301 1997	Interim Report on Testing Program
March through July, 1997	Identify & Finalize Demonstration Site
July through August, 1997	Conduct Demonstration
October 31, 1997	Interim Report on Demonstration
September, 1997 through October, 1998	Monitor Demonstration Site
Noverber 30, 1998	Draft Final Report
December 31, 1998	Final Report

Progress on the project will be reported through brief quarterly reports. These reports will be submitted to North Dakota Industrial Commission and the U.S. Department of Energy after review by MDU personnel. The first quarterly report will be made to coincide with the U.S. DOE reporting schedule in order to minimize the reporting requirements. Teleconference calls with MDU personnel, Western Research Institute personnel and ND Industrial Commission will take place as the need arises. The first quarterly report will be delivered on or before the 10th of the month on a quarterly basis, starting January, 1997. An Interim report covering the results of the laboratory testing program will be delivered by the end of July, 1997 while the interim report on the demonstration will be delivered by end of October, 1997. The Draft Final report will be delivered by end of November, 1998 with the final version due the end of December, 1998.

8.0 BUDGET AND MATCHING FUNDS

The estimated costs to conduct the marketing and demonstration program as described in the proposal is $152.633. The costs for the program are to be shared by MDU, ND Industrial Commission and WRI through its Cooperative Agreement with the US Department of Energy (METC). A summary of the project costs are presented in Table 4. Detailed budget information including the nature of the cost estimating procedures are in presented in Appendix D.

MDU will contribute $13,676 in cash above its earlier expenditures of $15,431. MDU will also contribute an estimated $29,000 of in-kind services and personnel associated with the market assessment, demonstration activities and project management and reporting. This also includes the costs of construction and materials for the demonstration that will be made available to the project, as in-kind services. It is requested that the ND Industrial Commission provide $37,319.

And finally, WRI and U.S. DOE will match both the MDU and ND Industrial Commission for the amount of $72,637. Such cost sharing by WRI will require the approval of the Morgantown Energy Technology Center, but is not expected to be a problem.

Table 4.
Summary of Project Estimated Costs

Funding Agencies	*Task 1 Market Evaluations*	*Task 2 Laboratory Testing*	*Task 3 Construct Demonstration*	*Task 4 Monitoring Activities*	*Task 5 Reporting & Management*	*Total Project*
Labor						
NDIC	$2,137	$4,544	$10.777	$6,633	$6,018	$30,119
DOE & MDU	$2.529	$29,094	$1.897	$20,188	$6.456	$60,163
Total	$4,666	$33,647	$12.674	$26,821	$12.474	$90.283
Supplies						
NDIC			$1,500		$200	$1,700
DOE & MDU		$500		$1,500	$300	$2,300
Total	$0	$500	$1.500	$1,500	$500	$4,000
Equipment						
Total	none	none	none	none	none	$0
Travel						
NDIC	$1.500		$4,000			$5,500
DOE & MDU	$1,000		$1.000	$6,600		$8,600
Total	$2.500		$5.000	$6,600		$14,100
Analytical						
NDIC						$0
DOE & MDU		$2.500		$3,500		$6,000
Total		$2,500		$3,500		$6,000
Sub-Contracts						
NDIC						$0
DOE & MDU			$1.000	$1.000		$2,000
Total			$1,000	$1,000		$2.000
In-Kind Services						
NDIC						$0
DOE & MDU	$7,000		$14.000		$8,000	$29,000
Total	$7,000		$14.000		$8.000	$29,000
Fees						
NDIC						$0
DOE & MDU	$3.000		$4.250	$4,250		$7.250
Total	$3.000			$4,250		$7,250
Total Costs						
NDIC	$3,637	$4,554	$16.277	$6,633	$6,218	$37,319
DOE & MDU	$13.529	$32.094	$17.897	$37,038	$14,756	$115.314
Total	$17,166	$36.647	$34.174	$43,671	$20.974	$152.633

(1) Includes Fringe Benefits, Labor Overhead Costs and G&A Overhead.

10.0 TAX LIABILITY STATEMENT

Neither Montana-Dakota Utilities nor Western Research Institute have any outstanding tax liability with the State of North Dakota. Affidavits for MDU and WRI are provided in Appendix D.

11.0 CONFIDENTIAL INFORMATION

None of the information in this proposal is considered confidential.

12.0 RELEVANT REFERENCES

Adaska, W.S. and W.C. Krell, 1992, "Bibliography on Controlled Low-Strength Materials (CLSM)", Concrete International, Vol. 14, No. 10, p. 42-43.

Ambroise, J., Amoura, A. and J. Pera, 1995, Development of Flowable High Volume-Fly Ash Mortars; *In Proceedings of the 11th International Symposium on Use and Management of Coal Combustion By-Products (CCBs),* American Coal Ash Association, EPRI TR-104657, p.38-1 - 38-9.

American Concrete Institute, 1994, Controlled Low-Strength Material, ACI SP-150.

American Concrete Institute, 1994, "State-of-the-Art Report on Controlled Low Strength Materials (CLSM)" ACI Committee 229 Report,.

ASTM, Annual Book of ASTM Standards, Philadelphia, PA.

Bacher, J. R. and R. L. Kolkka, 1991, "Design Applications with Flowable Fly Ash Backfill - Indian River Power Station"; *In Proceedings of the 9th International Symposium on Ash Utilization*, Orlando, FL, January, 1991, p. 7-1 to 7-15.

Balsamo, N., 1987, "Slurry Backfills - Useful and Versatile"; Public Works, April, 1987, p. 58-60.

Bhat, S.T., L:ovell, C.W., Scholer, C.F. and T.E. Nantung, 1995, Flowable Fill Using Waste Foundry Sand, Proceedings of the 11th International Symposium on Use and Management of Coal Combustion By-Products (CCBs), American Coal Ash Association, EPRI TR-104657, p.39-1 - 39-14.

Brewer, W.E., Schroeder, M. and D. Hirsch, 1995, Results of the Georgetown, Ohio Pavement Research Using Controlled Low Strength Material - Controlled Pavement Base; *In Proceedings of the 11th International Symposium on Use and Management of Coal Combustion By-Products (CCBs)*, American Coal Ash Association, EPRI TR-104657, p.42-1 - 42-12.

Brewer, W. E., 1992, "An Assemblage of Five Reports on the Subject of Controlled Low Strength Material (CLSM)", Cincinnati Gas and Electric Company, Cincinnati, Ohio.

Brendel, G. F., N. J. Balsamo and P. E. Glogowski, 1987, "An Overview of the Use of Fly Ash in Slurried Placement Applications"; *In Proceedings of the 8th International Symposium on Ash Utilization*, Washington, DC, October, 1987, p. 10-1 to 10-9.

Collins, R. J., J. J. Colussi and L. M. Ruggiano, 1991, "Physical Considerations in the Design, Mixing and Placement of Flowable Fill Materials"; *In Proceedings of the 9th International Symposium on Ash Utilization*, Orlando, FL, January, 1991, p. 6-1 to 6-14.

Electric Power Research Institute, 1988, "Laboratory Testing of Fly Ash Slurry"; *Electric Power Research Institute, Report No. CS-6100*, Palo Alto, CA, December 1988, 484 pp.

Fuston, J. J., W. C. Krell, and F. V. Zimmer, 1984, "Flowable Fly Ash: A New Cement Stabilized Backfill"; ASCE, Civil Engineering, March 1984, p. 48-51.

Grace Construction Products, 1996, "Darafill, Flowable Fill Performance Additive", W.R. Grace Co., Bedford Park, Illinois.

Kuloszewski, J.A., 1995, "Strength Testing of Flowable Ash Mixtures"; *In Proceedings of the 11th International Symposium on Use and Management of Coal Combustion By-Products (CCBs)*, American Coal Ash Association, EPRI TR-104657, p.40-1 -40-10.

Larsen, R. L., 1990, "Sound Uses of CLSM's in the Environment"; Concrete International, July 1990, p. 26-29.

Maher, M. H. and P. N. Balaguru, 1991, "Mechanical Properties of Low Strength, High Volume Fly Ash Mortar"; *In Proceedings of the 9th International Symposium on Ash Utilization*, Orlando, FL, January, 1991, p. 8-1 to 8-17.

McLaren, R. J., and N. J. Balsamo, 1989, "Fly Ash Design Manual for Road and Site Applications. Volume 2. Slurried Placement"; *Electric Power Research Institute, Report No.CS-4419*, Palo Alto, CA, October, 1989.

Mings, M. L., 1985, "Pipe Bedding with Class 'C' Fly Ash Grout"; *In Proceedings of the 7th International Ash Utilization Symposium and Exposition*, Orlando, FL, March 4-7, 1985, Volume I, DOE/METC-85/6018.

Naik, T. R., L. E. Sohns, and B. W. Ramme, 1991, "Controlled Low Strength Material (CLSM) Produced with High-Lime Fly Ash"; *In Proceedings of the 9th International Symposium on Ash Utilization*, Orlando, FL, January, 1991, p. 9-1 to 9-18.

Naik, T. R., B. W. Ramme and H. J., Kolbeck, 1990, "Filling Abandoned Underground Facilities with CLSM Fly Ash Slurry"; Concrete International, July, 1990, p. 19-25.

Nantung, T.E., 1993, "Design Criteria for Controlled Low Strength Materials", Ph.D. Thesis, Purdue University.

National Ready Mix Concrete Association, "Ready Mixed Flowable Fill - A Controlled Density Material"; NRMCA Publication MSP36, 4 pp.

Newman, F.B., DiGioia, Jr., A.M. and L.F. Rojas-Gonzalez, 1995, "CLSM Backfills for Bridge Abutments"; *In Proceedings of the 11th International Symposium on Use and Management of Coal Combustion By-Products (CCBs)*, American Coal Ash Association, EPRI TR-104657, p.4-1 -41-19.

Newman, F.B., Rojas-Gonzalez, L.F. and D.L. Knott, 1992, "Current Practice in Design and Use of Flowable Backfills for Highway and Bridge Construction", Pennsylvanua Department of Transportation Research Project 90-12.

Russ, W. E., 1987, "Flowable Mortar in Iowa"; *In Proceedings of the 8th International Symposium on Ash Utilization*, Washington, DC, October, 1987, p. 11-1 to 11-17.

Swaffer, K. M. and H. R. Price, 1987, "Tunnel Saved By Fly Ash', ASCE, Civil Engineering, September 1987, p. 69-70.

Torrey, S. 1978, "Fly Ash, Bottom Ash and Slag - The K-Krete Story"; Noyes Data Corporation, 1978, p. 119-122.

Weber, L., 1987, "Controlled Density Low Strength Material Backfill in Illinois"; *In Proceedings of the 8th International Symposium on Ash Utilization*, Washington, DC, January, 1987, p. 12-1 to 12-13.