UNIVERSITY OF UND NORTH DAKOTA

THE INSTITUTE FOR ENERGY STUDIES
UPSON II ROOM 366
243 CENTENNIAL DRIVE STOP 8153
GRAND FORKS ND 58202-8153
(701) 777-2533
und.instituteforenergystudies@engr.und.edu

April 1, 2012

Karlene Fine, Executive Director
North Dakota Industrial Commission
State Capitol – 14th Floor
600 East Boulevard Ave Dept 405
Bismarck, ND 58505-0840

ATTN: Lignite Research Program

RE: Approval of proposal

Dear Ms. Fine,

This is to confirm that the research proposal "Geomechanical Study of Harmon Lignite and Surrounding Rocks for Underground Coal Gasification in Western North Dakota" prepared by Dr. Zhengwen Zeng, Associate Professor in the Department of Geology and Geological Engineering at The University of North Dakota, submitted to you for the research grant at the Lignite Research Program under the North Dakota Industrial Commission, has been reviewed and approved by all related administrative officers in The University of North Dakota. If you have any questions on this proposal, please feel free to contact us.

Thank you very much.

Sincerely,

Dr. Zhengwen Zeng
Associate Professor

Barry I. Milavetz, PhD
Associate Vice President for
Research and Economic
Development

Proposal

Geomechanical Study of Harmon Lignite and Surrounding Rocks for Underground Coal Gasification in Western North Dakota

Submitted to:

Karlene Fine, Executive Director
North Dakota Industrial Commission (NDIC)
State Capitol-14th Floor
600 East Boulevard Ave Dept. 405
Bismarck, ND 58505-0804
ATTN: Lignite Research Program

Submitted by:

Zhengwen Zeng (PI, Ph.D., Assoc. Prof.)
Steven A. Benson (co-PI, Ph.D. Professor)
Scott F. Korom (co PI, Ph.D., Assoc. Prof.)
Institute for Energy Studies
Department of Petroleum Engineering
School of Engineering & Mines
University of North Dakota

Total proposed amount: $485,712
NDIC Lignite research program: $242,729
Industrial matching fund: $242,729

Dr. Zhengwen Zeng, Associate Professor, Geology
Geologic Engineering

Dr. Barry I. Milavetz, Director
Research Development and Compliance

April 1, 2012

Table of Contents

Abstract

Underground coal gasification (UCG) is a technology that has the potential to utilize the huge economically unmineable lignite resources in North Dakota. However, the current understanding of the geomechanical and petrophysical properties of the lignite-bearing formation in North Dakota is not sufficient to properly design a UCG process to convert the lignite to a gas. Based on preliminary research conducted by the University of North Dakota's (UND) Geology and Geological Engineering Department (GGE) on this topic since 2009 and suggestions of our industry partner, we propose to study the feasibility of UCG of deep Harmon lignite and the properties of associated strata. We plan to investigate the properties, the in-situ stress fields, and changes due to gasification of the coal-bearing formation, through laboratory testing and geomechanical and petrophysical analysis on core samples. The information derived from this testing will be used to evaluate the stability of the UCG cavities and wellbores, coal conversion factors, and the potential influences of the UCG site on groundwater resources in associated formations. Successful completion of this project will generate three major results: (1) a potential UCG site, (2) key mechanical and environmental responses of the UCG-impacted formations, and (3) a procedure to characterize the potential UCG sites in North Dakota.

This study is expected to be finished in two years. Participants include faculty, staff, and graduate students from UND. Methodologies and procedures developed in this feasibility study will provide valuable and fundamental information for long term

UCG projects that utilize lignite resources in North Dakota.

Project Summary

The objective of this project is to determine the technical feasibility of the Harmon lignite-bearing formation as a site for UCG. This will be accomplished by performing a geomechanical examination of the deep Harmon lignite and its neighboring strata that have been exposed to simulated UCG process conditions. The thick and relatively continuous Harmon lignite bed deep beneath western North Dakota provides a potential opportunity of using UCG technology to economically recover these resources. However, risks associated with UCG need to be evaluated. These risks include: subsidence, groundwater influx, and aquifer contamination (Sury et al., 2004; Burton et al., 2009). During the gasification process, in-situ stress field of the coal-bearing formation as a result of excavation process (transformation of the carbon to gas creating a cavity) due high gasification temperatures (~1000°C). Finding the right site is critically important. Stress concentration around gasification cavities can generate fractures hence reducing the strength of the rocks, providing transport paths for contaminants, and subsidence. At elevated temperatures, coal and associated sediments undergo physical and chemical changes that depend upon the coal reactivity, permeability, coal fracturing, roof stability, and heat loss to overburden (Shoemaker et al, 1978). Understanding the factors that impacts these chemical and physical processes for ND lignite UCG applications is essential in controlling the conversion process and in analyzing the geomechanical and petrophysical processes under different combinations of UCG operating parameter. In a UCG plant of commercial scale, multiple gasification cavities are set up as an array of "parallel tunnels". The induced stress fields of these cavities interact with each other and effect roof stability. Design of the cavity size and spacing is based on the geomechanical and petrophysical properties of the formation, and significantly influences the economics of the UCG plant. In general, the thermal and mechanical response of the formation during the UCG process is complex, presenting challenges in evaluating the site stability, recovery factor, contaminant remediation, and product gas flow through coal seam. Therefore, detailed knowledge about the geomechanical, petrophysical and hydrogeological characteristics of the coal-bearing formation and its neighboring strata is necessary. Based on the recent studies at UND on UCG indicate that, based on the preliminary site screening criteria, there are suitable UCG sites in North Dakota. The next steps include: identifying an appropriate UCG site, obtaining physical samples, characterizing the samples, and modeling the feasibility of the process.

The goal of this proposed study is to identify and select a "model" UCG site. In order to meet this goal the following tasks must be completed: (1) collect, collate and compile data from previous work, (2) obtain cores of the lignite bed and associated strata from the model site, (3) test related physical and chemical (geomechanical, petrophysical, hydrogeological, thermal) properties of the samples, (4) perform geomechanical numerical modeling of the site, and (5) report on the technical feasibility of UCG of North Dakota lignite.

Project Description

The project addresses the geomechanical challenges associated with the application of UCG to North Dakota lignite. Currently, the properties of the lignite-bearing formation with respect to UCG are not understood. Successful completion of this project will generate a better understanding of the geomechanical properties of the formation, and its response to the gasification process. These efforts are focused on developing a better understanding of the physical and chemical changes of the lignite and lignite-bearing strata during the UCG process. This includes developing information on coal reactivity, permeability, coal fracturing, roof stability, and heat loss to overburden. The environmental issues of UCG are important; the one we propose to consider is the likelihood that UCG will influence groundwater resources in associated formations.

An overview of the project is illustrated in Figure 1. The project consist of selection of a site, coring of site to obtain samples, characterization of samples, modeling of UCG site, and preparation of final report. The following lists the project objectives, methodology (scope of work), and anticipated results.

Objectives

1. Select UCG site in North Dakota for sampling and analysis
2. Obtain physical rock properties of the lignite bed and surrounding strata, and

predict their changes due to gasification process.

3. Develop a comprehensive report on site selection criteria, groundwater quality impact, syngas quality, and potential for UCG in North Dakota.

Methodology

Task 1. UCG Site Selection

Although the Fort Union Formation lignite resource in the Williston Basin of North Dakota has been investigated extensively, previous work was not focused on UCG applications. In this project, existing data relevant to Harmon lignite and surrounding strata will be collected and collated. For example, previous work may include reports, theses and dissertations, papers, survey data, well logs, and rock samples from the North Dakota Geological Survey (NDGS), U.S. Geological Survey (USGS), National Coal Resources Data System (NCRDS), North Dakota State Water Commission, North Dakota Oil and Gas Division, UND's Department of Geology and Geological Engineering, energy and utility companies. Existing literature covers a wide range of topics, including resources assessment, lignite quality, depositional environment, aquifers, surface gasification of North Dakota lignite, topography, land use, and ownership.

- Data collection and analysis- analysis of existing information on the formation in the region of interest will be examined.
- Preliminary 3-D geological and hydrogeological modeling of potential sites

will be performed.

- Site selection – selection will be made based on sponsors input and key geologic and hydrogeological information.

Task 2. Collect coal and rock samples from drill cores of formation

A drilling company, Interstate Drilling Services will perform the drilling under the direction of UND. Samples will be described in detail to provide a description of the stratigraphic sequence. Samples that will be analyzed include overburden, lignite bed, overburden/underlying strata, and specimens with joints and discontinuities.

Task 3. Testing and characterization of overburden and lignite

The lignite will be analyzed to determine the proximate, ultimate, heating value, and ash composition. This information will be used to assess the gasification potential of the coal. Selected lignite, overburden, and underlain strata pecimens will be tested under different stress and temperature conditions for parameters which will enable simulating the gasification process. Existing reaction chambers available in the Chemical Engineering Department will be used to expose samples to gasification conditions typical of the conditions in UCG. Once the samples are produced they will be characterized.

- In-situ stress determination.
- Porosity measurement by Boyle's law.
- Permeability measurement by Darcy's law and transient techniques.
- Measurement of dynamic Young's modulus and dynamic Poison's ratio by

ultrasonic P- and S-wave velocity test.

- Tensile test.
- Uniaxial compression test.
- Triaxial compression tests.
- Triaxial extension tests.
- Viscoelastic test (compression and extension tests at elevated temperature).
- Measurement of other thermo-elastic and petrophysical properties.

A list of key parameters that will be derived from the measurements are summarized in Table 1. The test results will be used to predict the thermal and mechanical response of the formation for the UCG process. Results of this work will provide detailed and fundamental knowledge for process design, risk prediction and economic evaluation in UCG projects in North Dakota.

Table 1: Physical rock parameters to be obtained in the study

Strength	tensile, uniaxial compression, triaxial compression, triaxial extension, and fracture toughness
Elasticity	Young's modulus, Poisson's ratio, bulk modulus, shear modulus
Thermoelasticity	thermal expansion coefficient, heat conductivity, heat convection coefficient, heat capacity
Poroelasticity	Biot coefficient
Petrophysics	porosity, permeability, density
In-situ stress	hydrostatic pressure, in-situ stress

Task 4. Numerical modeling

As listed in Figure 1, geomechanical numerical modeling of the formation response to UCG processes will be evaluated. UND builds on related work conducted that can be applied to the UCG. The past work has included reservoir characterization, in-situ stress analysis, hydraulic fracturing, directional well drilling and enhanced oil recovery through in-situ combustion. Our previous study in UCG and related areas is referred to in Appendix 2. Through previous geomechanical work is in related areas, our research team has been trained numeric modeling methods. In addition to the geomechanical modeling various gasification models described by Benson and Sondreal (2010) will be used to predict lignite conversion and the composition of the syngas produced under a range of conditions. This information will also be used to estimate conversion rates. We will apply these techniques as follows:

- Modeling the stress and temperature field of a single UCG cavity, and evaluate its stability.
- Modeling a commercial UCG plant which has multiple gasification cavities
- Based on the obtained transport properties, primarily predicting possible contaminants transport route. Assessing the potential influence on groundwater resources in the area.
- Based on modeling results of stress field, predicting allowable range of temperature and pressure for gasification reactions, assessing the how the chemical reactions would be influenced.
- Evaluate the structural stability and coal recovery factor.

Task 5. Reporting

The following activities will track progress and document the results of this work.

a. Meetings/conference calls to discuss all results, conclusions, and recommendations. These will be made at a minimum on a monthly basis during the course of the project.

b. Report on recommendation of drilling site

c. Writing and submission of draft task reports will be submitted in accordance with the project schedule.

d. Writing and submission of a Final report to project sponsors.

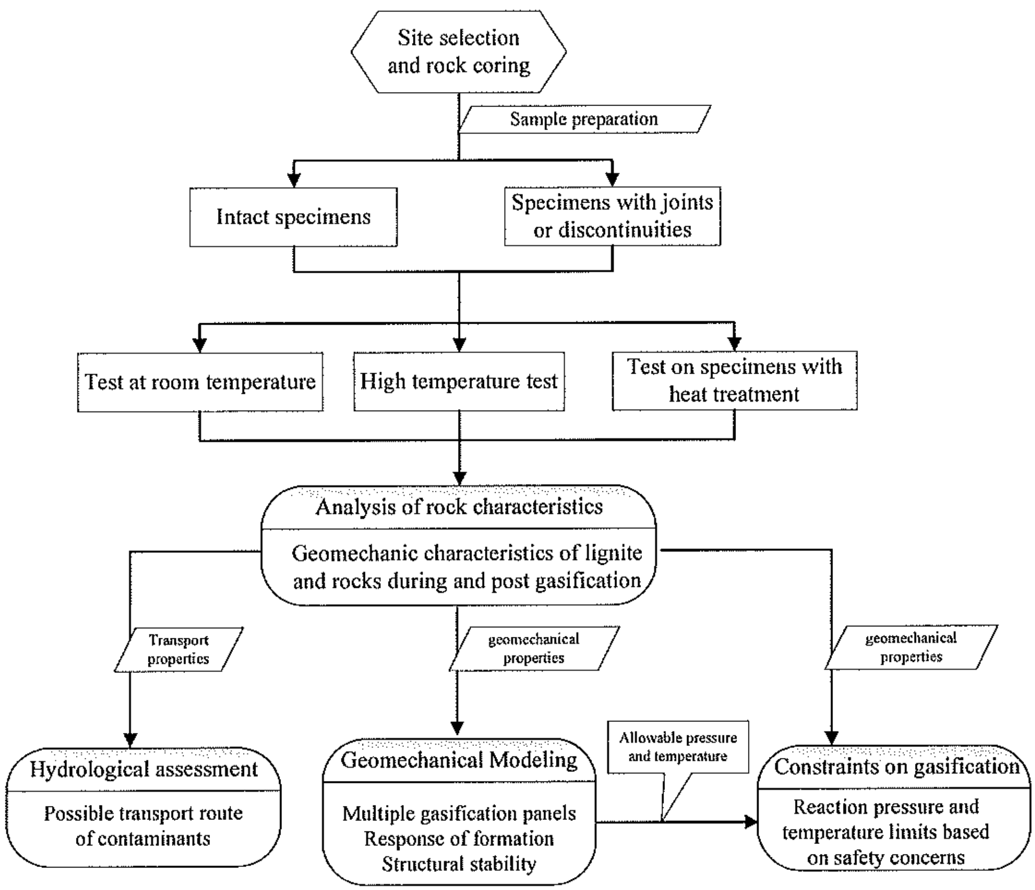

Figure 1. Flowchart of the proposed project.

Deliverables

The key deliverables will consist of task reports and a final report conducted through the course of the project. The work will provide include the following key components:

1. Identification of a model UCG site in North Dakota.
2. Physical properties of the coal and surrounding strata (Table 1).
3. Changes of properties with the alternation of stress and temperature as a result of exposure to UCG conditions.
4. Site selection criteria, groundwater quality impact, syngas quality, and potential for UCG in North Dakota.

Standards of Success

1. Model UCG site identified and sampled.
2. Detailed characterization and analysis of site samples completed.
3. Numerical modeling of site complete
4. Reliable, reasonable and representative data generated from experimental and numerical modeling.
5. Reporting completed through papers, reports and conference presentations.

Background

Lignite Gasification and Reactivity

Successful surface gasification of lignites has been taking place for over 100 years. Early gasification was associated with producing gas for lighting in town gas sites throughout the United States. Lignite was a fuel that was utilized to produce town gas in several locations. Large-scale commercial gasification of lignite began in 1984 with the commissioning of the Dakota Gasification Plant. The Dakota Gasification Company (DGC) Great Plains Synfuels Plant (GPSP) is the only commercial coal gasification process that produces methane in the United States. The plant has operated successfully for over 25 years.

The reactions of lignite coals in surface gasification are greatly influenced by properties that distinguish them from bituminous coals; technologies developed primarily for bituminous coals often need to be modified to operate satisfactorily on low-rank fuels (Benson and Sondreal, 2010). Properties of low-rank coals that differ significantly from those of bituminous coals include molecular and physical structure; high moisture content; low heating value; dissimilar contents and forms of oxygen, sulfur, and nitrogen; higher porosity and surface area; higher reactivity in oxidizing and reducing atmospheres; high gas and low tar yields in pyrolysis; distinctive (alkaline) inorganic forms and mineral contents; uniquely different physical and chemical transformations of char and inorganic intermediates in combustion and gasification systems; and distinctive ash deposition mechanisms, slag viscosity behavior, and corrosion mechanisms. These unique low-rank coal properties as applied to the various types of gasification systems raise a number of key issues which impact the utilization of the resource.

Key issues for gasification of lignite coal (Low-Rank Coal Study, 1980) that have the potential to impact utilization in underground coal gasification are as follows: high coal reactivity, non-caking characteristics, presence of alkali and alkaline earth elements that catalyze carbon conversion, and high oxygen contents that effect reaction rates.

Lignites from North Dakota have shown high reactivities at elevated temperatures in both oxidizing (Smith and others, 1993) and reducing (Timpe and others, 1989a,b) atmospheres, but this reactivity does not correlate with surface area measurements. The high reactivity of lignite in thermal processes can be attributed to the abundance of free radicals formed from the oxygen functionalities in low-rank coals during thermal transformations such as decarboxylation. These free radicals either react rapidly with gaseous agents, or they mutually coalesce to form the highly cross-linked solid char (noncaking) that is characteristic of low-rank coal. The lack of softening upon heating allows free flow, mixing, and reaction at high temperatures. Differences in reactivity among low-rank coals can be attributed at least in part to the catalytic activity of minerals and ion-exchangeable cations. The addition of alkali or alkaline earths to coals of all ranks has been shown to catalyze gasification reactions, possibly by means of redox reactions whereby carbon reduces the alkali to metal, the metal reacts with water to release hydrogen, and the resulting alkali hydroxide combines with CO_2 to form alkali carbonate that reenters the catalyst cycle (Wood and Sancier, 1984).

Underground Coal Gasification

UCG converts coal in-situ into synthesis gas or syngas via the same chemical reactions that occur in surface gasifiers (Burton and others, 2006). UCG involves drilling wells into coal seams from the surface as illustrated in Figure 2. The wells are used to inject air or oxygen into the coal seam to combust part of the coal to produce heat that will drive the gasification reactions in situ. Wells are used to transport the syngas produced to the surface. At the surface, the syngas is processed for use for power generation or feedstocks for chemical and fuel production. The UCG processes are typically applied to deep coal seams that are not accessible to current mining methods. These coal deposits are at depths greater than 100 m and where the coal seam thickness is greater than 2 meters. The UCG-derived syngas typically has high hydrogen and carbon monoxide contents and low methane. Pollutants present in the syngas can be controlled using the same methods developed for surface gasification technologies. However, there are concerns related to groundwater: the reactor cavity is usually operated at less than hydrostatic pressure, which brings water into the gasification reaction zone, resulting in steam gasification reactions (Friedmann and others, 2009).

Approximately 85% of world coal resources are not economically minable by conventional mining methods. The UCG can utilize coal seams that are too deep to be economically mined, therefore significantly increasing global recoverable coal reserves. The Linc Energy Ltd. (2008) estimated that there is over 5 million pJ of resource of UCG syngas in the United States and over 2.2 million pJ of UCG syngas in China. The UCG holds several advantages such as lower capital investment costs, no handling of coal and solid wastes at the surface (ash remains in the underground cavity), no human labor or capital for underground coal mining, minimum surface disruption, no coal transportation costs, and direct use of water and feedstock available in situ (Shafirovich and Varma, 2009).

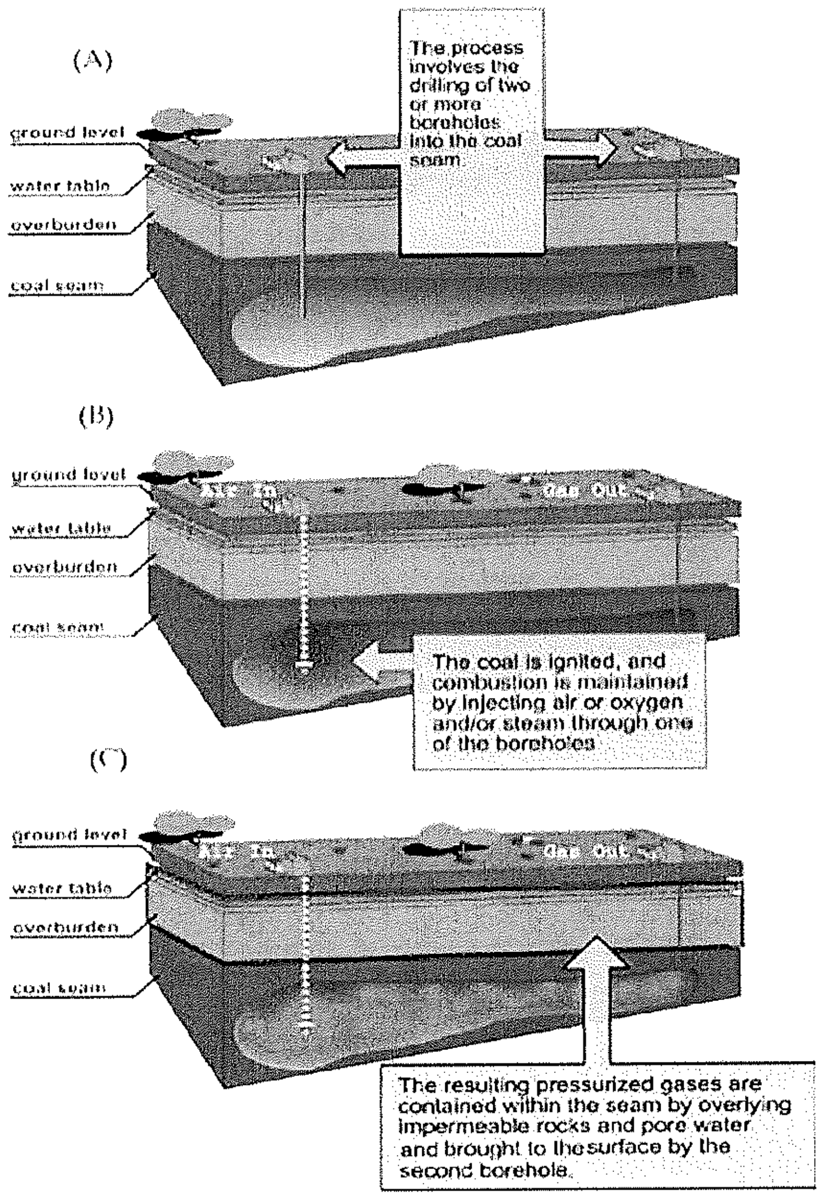

Figure 2. UCG process (Linc Energy Ltd., 2008).

Figure 3 shows where UCG activities have occurred in recent years. Several key engineering and environmental issues need to be resolved to commercialize the UCG technology. Based on a review of pertinent literature, there are four key technical issues for a successful UCG project: combustion control, wells linkage, site selection, and associated environmental issues. The UCG combustion process cannot be as well controlled as the designed gasifiers on the surface. Process parameters like the rate of water influx, the distribution of reactants in the gasification zone, and the growth rate of the cavity can only be estimated from measurements of temperatures and product gas quality and quantity. Variation of permeability affects the flow rate of injected reactants and products. Consequently, variation of the product volume and composition can introduce problems to the downflow utilization processes. Regarding a possible environmental issue, UCG may result in subsidence because of evacuation of coal seams and underground contamination because of exchange of underground fluids (Burton and others, 2006; Shafirovich and Varma, 2009).

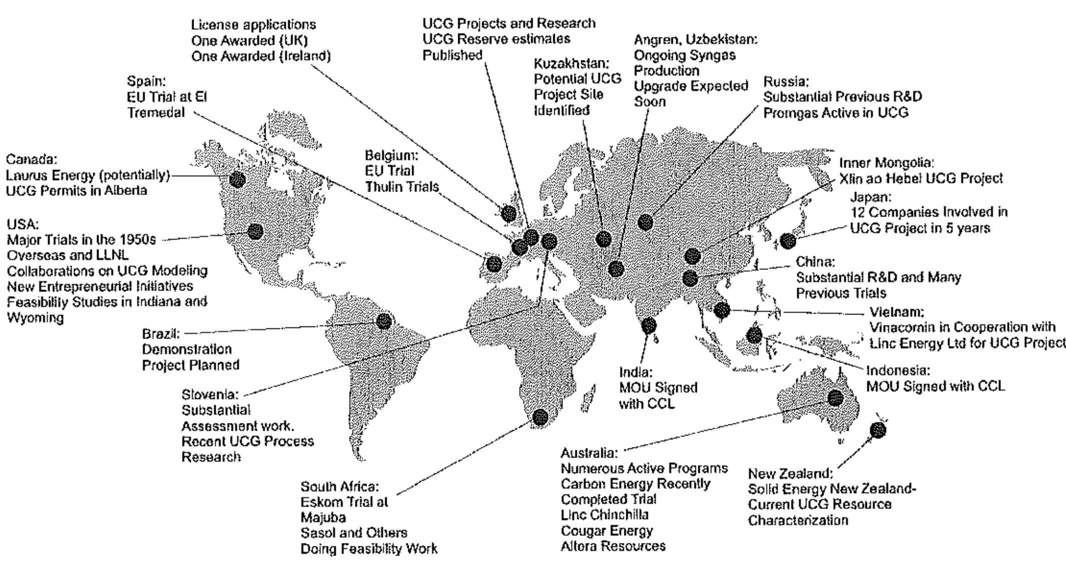

Figure 3. Global UCG activities in recent years (UCG Partnership, 2009).

Qualifications

Team

The research team will include 6 key members: (1) Dr. Zhengwen Zeng (PI, Associate Professor in Petroleum & Geological Engineering), (2) Dr. Steve Benson (co-PI, Professor in Petroleum & Chemical Engineering), (3) Dr. Scott Korom (Co-PI, Associate Professor in Petroleum & Geological Engineering), (4) Hong Liu (Research Lab Technician), (5) Peng Pei (PhD student in Geological Engineering track), and (6) Jun He (MS student in Geology).

Due to the importance of lignite in North Dakota, and the promising future of UCG technology for clean and sustainable energy, the PI has led some of the team members (Peng Pei, Jun He and Hong Liu) to investigate potential application of UCG in North Dakota from different aspects since 2009. Preliminary feasibility studies have been conducted on resource abundance, lignite seam depth and thickness, depositional environment, lithological compositions and site accessibility. We have carried out preliminary experimental study using rock samples collected from outcrops of the Harmon lignite-bearing formation and an analytical study about the cavity stability and recovery factor of a conceptual UCG plant. Conference papers and presentations have been published. Our preliminary research has prepared us and given us the incentive to conduct the proposed work.

Other faculty members on the research team include Drs. Steve Benson and Scott Korom, both are active research-oriented professors at UND. Dr. Steve Benson is an expert in fuel resources, with specialties in coal gasification, environmental protection, and multidisciplinary project management. He has many years of experience with the coal industry. He has strong background in chemical engineering, and has lab facilities and numerical modeling software packages related to coal gasification. His participation in this project will greatly enhance the team's capability in connection with the state and industry, and the application of state-of-the-art technology in modeling syngas quality. Dr. Scott Korom is an expert in hydrogeology and environmental engineering. He has worked with the North Dakota Department of Health and the North Dakota State Water Commission on groundwater quality issues. His expertise will greatly contribute to two of the key issues: groundwater protection and contaminants transport.

In summary, this team has included members that have all the necessary expertise and facilities to conduct the proposed research. Preliminary studies have generated good results, and a close relationship with the lignite industry, lignite council, and state agencies has been established.

Please refer to Appendix 1 for CVs of the faculty members.

Facilities

With the support from the U.S. Department of Energy, North Dakota Industrial Commission, North Dakota Department of Commerce's Center of Excellence Program and partners from the energy industry, the Petroleum Engineering Laboratory (http://www.und.edu/dept/pelab/) at The University of North Dakota is equipped with advanced experimental facilities and software packages, with the capacities to support the proposed research. These capacities, together with accessible resources in other departments on campus (e.g. Chemical Engineering) can well serve research activities about UCG.

1. Hardware

- *AutoLab 1500*

  This Triaxial laboratory test system can perform standard petrophysical and rock mechanic experiments, and measure most of the mechanical and petrophysical properties of formation rocks under formation pressure and temperature, such as bulk modulus, shear modulus, Young's modulus, Poisson's ratio, strength, permeability, resistivity, P- and S-wave velocities.

- *816 MTS Rock and Concrete Mechanic Testing System*

  This system has high-capacity, high-stiffness load frames and can perform uniaxial test for investigation of the complete deformation behavior of rock and concrete over a wide range of testing conditions.

- *Fluid-Rock Interactive Dynamics System (in-house developed)*

  The system can perform triaxial strength test, permeability test, seismic velocity test while fluid(s) flows through porous media.

- *Kaiser In-situ Stress System (in-house developed)*

  The system is used to determine the in-situ stress from rock samples using the Kaiser Effect.

- *High temperature furnace*

  The furnace is housed at the Department of Chemical Engineering and can simulate the high-temperature environment created during the gasification process.

- *High temperature triaxial test cell (to be developed)*

  This new system will be developed in this study and will be able to conduct the triaxial compression and extension test at elevated temperatures.

- *Thermal Exensometer (to be developed)*

  The thermal extensometer will be used to measure the thermal expansion coefficient of the rocks and lignite.

2. Software

- *Petra* (well log processing).
- *Interactive Petrophysics* (well log interpretation).
- *Petrel* (lignite reservoir characterization).
- *FLAC3D* (geomechanical analysis).
- *ANSYS* (geomechanical analysis).
- *Fluent* (fluid mechanics analysis).
- *Engineering Equation Solver* (thermodynamic analysis).

Value to North Dakota

As only 2% of the lignite reserves in North Dakota can be economically mined by conventional surface mining practices (Murphy, 2006), UCG technology is expected to provide a clean and efficient way to recover the huge resources. The UCG plant has a smaller footprint than surface gasification plants. High moisture content in the lignite is utilized as a reactant in the gasification process, instead of functioning as a barrier during combustion in boilers. The produced syngas is versatile and can be used to generate electricity or upgrade to various chemical products and clean fuels such as hydrogen, substitute natural gas or liquid fuel through the Fischer-Tropsch process. Such a long industry chain can generate job opportunities and tax revenues for the state. Successful UCG projects will help convert lignite resources beneath North Dakota into huge economic benefits.

More than 30 UCG trial projects were conducted in the U.S. during 1970 – 1980s, but currently no commercial or trial project is in actual operation. Environmental issues and disappointing economic returns were the major issues. However, in recent decades, thanks to great technological advances such directional drilling, process monitoring, well linkage and computer modeling, UCG technology has received renascent interest and successful UCG projects are conducted in Australia and South Africa (Shafirovich and Varma, 2009; Burton et al, 2009). These projects have provided huge economic and environmental benefits, as well as valuable information concerning UCG site selection, process design and operation. With the significant unmineable lignite resource, North Dakota can also become a leader in the application of UCG and other clean coal technologies, and help to contribute the "Energy Independence" of the United States. The results of this project will fill the gap between the current knowledge of the Harmon lignite-bearing beds and the needed investigation to UCG feasibility. Completing this project will bring better understandings to the Harmon lignite beds and adjacent rocks and strata from the view of UCG application. The experimental and modeling results will provide support to UCG site selection, risk assessment and performance evaluation, and help investors design environmental friendly and profitable UCG projects. Such information would be another attraction to potential investors besides the lignite resource itself.

Management

The project will have five tasks: (1) UCG Site selection, (2) Collect coal and rock samples from drill cores of formation, (3) testing and characterization, (4) numerical modeling, and (5) Reporting, each with 3 sub-tasks (Table 2). Task 1 will be conducted by all team members. Key players of Task 2 will be Zeng, He, Liu, and Peng. Key players of Tasks 3 and 4 will be Zeng, Benson, Korom and Peng. Task 5 will be conducted by all members.

The project is scheduled to be completed in two years, with a targeted starting date on July 1, 2012. Task 1 will last in 3 quarters (9-months), with the target that model UCG site can be located, and samples could be obtained. Task 2 will start in the third quarter of the project, and continue for one year. The one quarter overlap between Tasks 1 and 2 is to prepare the facilities, techniques and verifying the methods. Task 3 will generate the key coal and rock properties that will allow the team to perform the numerical modeling required by the following task.. Task 4 is to numerically model the outcomes of the UCG processes, including the failure and subsidence of the rock strata and the coal seam, the control of contaminant transportation into the groundwater, and the syngas quality. It is scheduled to last for three quarters, starting at the 5^{th} quarter of the project's commence. Task 4 is comprehensive, numerical analysis study to integrate the results to generate some specific results for the model UCG site, and general conclusions about the application of UCG technology, and its potential in North Dakota. It will be conducted in the last two quarters of the project. Reporting is considered as Task 5. It will start at project initiation and continue until the end of the project. Table 2 details the tasks and subtasks, as well as key players for each task.

This research team and the lab has been successfully completing research projects related to CO_2 sequestration in Williston Basin, and Bakken geomechanical study for improved oil recovery in Williston basin, North Dakota. We have established good ties with USGS, NDGS, and other related agencies for research data, rock samples, and other technical support. We believe our success will continue with the lignite UCG research planned in this proposal.

Table 2. Tasks and timetable.

Tasks (key players)	2012		2013				2014	
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
1,2. Site selection and sampling (all)	• Data collection • Coal geology • Sample collection							
3. Testing and Characterization (ZZ, JH, HL, & PP)			• Preparation • Testing • Data reduction and interpretation					
4. Numerical Modeling and analysis (ZZ, SB, SK, & PP)					• Single/multiple UCG panel • Groundwater quality • Syngas quality			
							• Site criteria • UCG potential	
5. Reporting (all)	• Research reports (progress and final) • Papers (conference and journals) • Presentations (meetings and invited)							

Budget Plan

The budget plan includes: 1) Total budget, 2) Yearly budget, and 3) Budget notes. The total budget is the combination of the budgets in each year from both NDIC and industrial partners. As required by the NDIC Lignite Research Program, the budget is designed to have 1-to-1 matching funds; i.e., the same amount of funding amounts from NDIC and from the industry partners are planned. The current F&A Rate at UND is 38%.

To include our industrial partner's feedbacks to a maximum degree, initially one well is proposed to be drilled on the model UCG site through subcontract an option for three drill core samples is provided in Appendix 5. A quote for drilling and coring cost from a Grand Forks, ND company has been obtained. Using the wells, samples of the lignite, the neighboring strata, and ground water will be obtained. If multiple wells are drilled as budgeted in the options These wells will provide a decent coverage on the geological and hydrogeological information for the model UCG site model. The quote for the high temperature loading cell was based on oral conversation with a manufacturer in the recent SPE annual conference in Denver, CO. It will allow us to test the coal and rock physical properties and chemical behavior at elevated temperatures so as to build the prediction model for higher temperatures. The following pages show the details for the total budget, the yearly budget, and the budget notes.

Total budget

BUDGET OUTLINE	F&A =	0.38	
DESCRIPTION	YEAR 1	YEAR 2	TOTAL
SALARIES - REGULAR	34,122	33,154	67,276
SALARIES - OTHER	45,600	47,400	93,000
SALARIES - FACULTY	20,263	21,276	41,539
FRINGE BENEFITS	18,095	17,925	36,020
			0
TOTAL PERSONNEL	118,080	119,755	237,835
			0
TRAVEL	2,000	2,000	4,000
COMMUNICATIONS-PHONE	0	0	0
COMMUNICATIONS-POSTAGE	200	200	400
INSURANCE	0	0	0
RENTS/LEASES-EQUIPMENT & OTHER	200	200	400
RENTS/LEASES-BUILDING/LAND	0	0	0
OFFICE SUPPLIES	200	200	400
PRINTING-COPIES, DUPLICATING	200	200	400
REPAIRS	0	0	0
UTILITIES	0	0	0
SUPPLIES-IT SOFTWARE	200	200	400
SUPPLY/MATERIALS-PROFESSIONAL	200	200	400
SUPPLIES-MISCELLANEOUS	1,000	2,000	3,000
IT EQUIPMENT <$5,000	0	0	0
OTHER EQUIPMENT <$5,000	1,000	0	1,000
FEES-OPERATING FEES & SERVICES	0	0	0
FEES-PROFESSIONAL FEES & SERVICI	4,100	4,100	8,200
FEES-SUBCONTRACTS (see Note 1 belo	35,400	0	35,400
PROFESSIONAL DEVELOPMENT	200	200	400
FOOD AND CLOTHING	500	500	1,000
WAIVERS/SCHOLARSHPS/FELLOWSHI	30,000	30,000	60,000
			0
TOTAL OPERATING	75,400	40,000	115,400
			0
EQUIPMENT >$5,000	25,000	0	25,000
IT EQUIPMENT >$5,000	0	0	0
			0
TOTAL EQUIPMENT	25,000	0	25,000
			0
TOTAL DIRECT COST	218,480	159,755	378,235
			0
F&A (INDIRECT COST) *	58,171	49,307	107,477
			0
TOTAL COST	276,651	209,062	485,712

Yearly budget

Year 1

Item	Rate($)	Quantity	NDIC	Industry
Personnel				
Salary				
Faculty1(PI)	8,904.00	1.00	4,452	4,452
Faculty2(co-PI)	12,086.00	0.50	3,022	3,022
Faculty3	10,632.00	0.50	2,658	2,658
Staff_Lab Technician	3,545.00	9.00	15,953	15,953
Staff_Administrative Support	3,695.00	0.60	1,109	1,109
Other_Graduate Research Assistant X 2	1,650.00	12.00	19,800	19,800
Other_Undergrad Research Assistant	500.00	12.00	3,000	3,000
Fringe benefits				
Faculty (PI)	0.20		890	890
Faculty2(co-PI)	0.20		604	604
Faculty3	0.20		532	532
Lab technician	0.35		5,583	5,583
Administrative Support	0.35		388	388
GRA x 2	750.00	2.00	750	750
URA	0.10	1.00	300	300
Total Personnel			59,040	59,040
Operational				
TRAVEL	2,000.00	1.00	1,000	1,000
COMMUNICATIONS-PHONE				
COMMUNICATIONS-POSTAGE	200.00	1.00	100	100
INSURANCE				
RENTS/LEASES-EQUIPMENT & OTHER	200.00	1.00	100	100
RENTS/LEASES-BUILDING/LAND				
OFFICE SUPPLIES	200.00	1.00	100	100
PRINTING-COPIES, DUPLICATING	200.00	1.00	100	100
REPAIRS				
UTILITIES				
SUPPLIES-IT SOFTWARE	200.00	1.00	100	100
SUPPLY/MATERIALS-PROFESSIONAL	200.00	1.00	100	100
SUPPLIES-MISCELLANEOUS	1,000.00	1.00	500	500
IT EQUIPMENT <$5,000	0.00	0.00	0	0
OTHER EQUIPMENT <$5,000	1,000.00	1.00	500	500
FEES-OPERATING FEES & SERVICES				
FEES-PROFESSIONAL FEES & SERVICES	4,100.00	1.00	2,050	2,050
FEES-SUBCONTRACTS	35,400.00	1.00	17,700	17,700
PROFESSIONAL DEVELOPMENT	200.00	1.00	100	100
FOOD AND CLOTHING	500.00	1.00	250	250
WAIVERS/SCHOLARSHPS/FELLOWSHPS	15,000.00	2.00	15,000	15,000
TOTAL OPERATING			37,700	37,700
EQUIPMENT >$5,000	50,000.00	0.50	12,500	12,500
IT EQUIPMENT >$5,000				
TOTAL EQUIPMENT			12,500	12,500
TOTAL DIRECT COST			109,240	109,240
F&A (INDIRECT COST) *			29,085	29,085
TOTAL COST			138,325	138,325
Y1 Total (State + Industry)				276,651

Year 2

Item	Rate($)	Quantity	NDIC	Industry
Personnel				
Salary				
Faculty (PI)	9,349.20	1.00	4,675	4,675
Faculty2(co-PI)	12,690.30	0.50	3,173	3,173
Faculty3	11,163.60	0.50	2,791	2,791
Staff_Lab Technician	3,425.10	9.00	15,413	15,413
Staff_Administrative Support	3,879.75	0.60	1,164	1,164
Other_Graduate Research Assistant X 2	1,725.00	12.00	20,700	20,700
Other_Undergrad Research Assistant	500.00	12.00	3,000	3,000
Fringe benefits				
Faculty (PI)	0.20		935	935
Faculty2(co-PI)	0.20		635	635
Faculty3	0.20		558	558
Lab technician	0.35		5,377	5,377
Administrative Support	0.35		407	407
GRA x 2	750.00	2.00	750	750
URA	0.10	1.00	300	300
Total Personnel			59,877	59,877
Operational				
TRAVEL	2,000.00	1.00	1,000	1,000
COMMUNICATIONS-PHONE				
COMMUNICATIONS-POSTAGE	200.00	1.00	100	100
INSURANCE				
RENTS/LEASES-EQUIPMENT & OTHER	200.00	1.00	100	100
RENTS/LEASES-BUILDING/LAND				
OFFICE SUPPLIES	200.00	1.00	100	100
PRINTING-COPIES, DUPLICATING	200.00	1.00	100	100
UTILITIES				
SUPPLIES-IT SOFTWARE	200.00	1.00	100	100
SUPPLY/MATERIALS-PROFESSIONAL	200.00	1.00	100	100
SUPPLIES-MISCELLANEOUS	1,000.00	2.00	1,000	1,000
IT EQUIPMENT <$5,000				
OTHER EQUIPMENT <$5,000				
FEES-OPERATING FEES & SERVICES				
FEES-PROFESSIONAL FEES & SERVICES	4,100.00	1.00	2,050	2,050
FEES-SUBCONTRACTS				
PROFESSIONAL DEVELOPMENT	200.00	1.00	100.00	100.00
FOOD AND CLOTHING	500.00	1.00	250.00	250.00
WAIVERS/SCHOLARSHPS/FELLOWSHPS	15,000.00	2.00	15,000	15,000
TOTAL OPERATING			20,000	20,000
EQUIPMENT >$5,000				
IT EQUIPMENT >$5,000				
TOTAL EQUIPMENT				
TOTAL DIRECT COST			79,877	79,877
F&A (INDIRECT COST)			24,653	24,653
TOTAL COST			104,531	104,531
Y2 Total (State + Industry)				209,062

Budget notes

The budget plan is developed using the UND standard template. Total budget is the combination of the budgets in each year. As required by the NDIC Lignite Research Program, the budget is designed to have 1-to-1 matching funds from industry; i.e., the same levels of funding from NDIC and the industry partner are planned. The current F&A Rate at UND is 38%. The following is an explanation on items noted in the detailed budget in each year.

1 Salary

UND faculty members are paid for 9-mo for their teaching, research and service in the fall and spring semesters. During the summer, the faculty may allocate coverage from research projects scheduled over the summer; summer salary is based on the faculty's nine month contract.

Salary was also included for administrative support to assist with the reporting and financial aspect of the project and a lab technician to assist with the research tasks.

A 5% annual increase is used for year 2 budget.

2 Fringe benefits

The UND standard formula is used.

3 Travel

Due to the fact that most active UCG projects are in foreign countries, both domestic and international travel are proposed.

4 Lab supplies

4 Lab supplies

This is mainly for lab consumables, including drill barrels, saw blades, grinding papers, cleaning towel papers, cleaning alcohols, strain gages, super glues, daily lab tools, etc.

5 Other Equipment <$5000: Thermal instrument

This is to be purchased for measurement of thermal expansion. No quote is received yet. Price is based on previous experience.

6 Fees-Subcontracts: Well for cores

Following industrial reviewer's suggestion, we proposed to drill 3 wells to have the minimum coverage on the model UCG site, and obtain the cores, as well as other geological and hydrogeological information, including groundwater samples. The quote was provided by Interstate drilling service, LLP, Grand Forks, ND (Appendix 3).

7 GRA tuitions

This is obtained from UND graduate school.

8 Equipment >$5000 High temperature loading cell

Following an industrial reviewer's suggestion, we proposed to add a high temperature (up to 600C) loading cell which will allow us to test and thus predict the changes of rock physical properties and chemical behaviors of lignite and rock at elevated temperatures.

9 Professional Fees: Analysis

This was included to allow for lignite and strata analysis.

Matching Funds

After initial review to our proposal, Great Northern Properties LP is interested in supporting this project by providing the needed matching fund. A letter of support is attached (Appendix 4).

Tax Liability

None

Confidential Information

None

References

- Benson, S.A. and Sondreal, E.A., Gasification of Lignites of North America, North Dakota Industrial Commission, 2010.
- Burton, E., J. Friedmann, and R. Upadhye. 2006. Best practice in underground coal gasification, Contract W-7405-Eng-48, Lawrence Livermore National Laboratory: Livermore, CA, USA.
- Friedmann, S.; Upadhye, R.; Kong, F. Prospect for Underground Coal Gasification in Carbon-Constrained World. *Energy Procedia* **2009**, *1*, 4551–4557.
- Linc Energy Ltd. Underground Coal Gasification: Industry Review and an Assessment of the Potential of UCG and UCG Value-Added Products. www.lincenergy.com.au/pdf/ ucgreport-01.pdf, 2008.
- *Low-Rank Coal Study*; National Needs for Resource Development. Technology Evaluation. Prepared for the U.S. Department of Energy Contract No. DE-AC18-79FC10066; Energy Resources Co. Inc., Walnut Creek, CA, Nov 1980.
- Murphy, E.C., N.W. Kruger, G.E. Goven, Q.L. Vandal, K.C. Jacobs, and M.L. Gutenkunst. 2006. The lignite resources of North Dakota, Report of Investigation No. 105. North Dakota Geological Survey (NDGS), Bismarck, North Dakota.
- Shafirovich, E., and V. Varma. 2009. Underground Coal Gasification: A brief review of current status, *Industrial and Engineering Chemistry Research,* 48: 7865-7875.
- Shoemaker, H., S. Advani, F. Gmeindi, and Y. Lin. 1978. The influence of bituminous coal and overburden Thermo-mechanical properties on subsidence associated with underground coal conversion, *ACE Fuel*, 23: 233-244.
- Smith, K.L.; Smoot, D.; Fletcher, T.H. Coal Characteristics, Structures, and Reaction Rates. In *Fundamentals of Coal Combustion;* Smoot, L.D., Ed.; Elsevier Publishing, 1993; p 131.
- Timpe, R.C. et al. Characterization of a Texas and North Dakota Lignite Char Used in the Production of Hydrogen. *J. Coal Quality*, **1989a**, *8* (1), 27.
- Timpe, R.C. et al. *Production of Hydrogen from Low-Rank Coals, Char Properties and Reactivity*; Topical Report for U.S. Department of Energy Cooperative Agreement No. DE-FC-86MC10637; 1989b.
- Sury, M., M. White, J. Kirton, P. Carr, R. Woodbridge, M. Mostade, R. Chappell, D. Hartwell, D. Hunt, and N. Rendell. 2004. Review of environmental issues of

underground coal gasification. Report COAL R272 DTI/Pub URN 04/1880. Department of Trade and Industry Technology (DTI), London, United Kingdom.

- UCG Partnership. 2009, www.ucgp.com/key-facts/basic-description/ (accessed January 2009).

- Wood. B.J; Sancier, K.M. The Mechanism of the Catalytic Gasification of Coal Char: A Critical Review. *Science Engineering* **1984**, *26* (2), 233.

Appendix 1: CVs of PI and other Faculty members

CV of Zhengwen Zeng, PI

Zhengwen Zeng, PhD, Associate Professor, Petroleum and Geological Engineering

Education

1. Ph.D. Petroleum & Geological Engineering, University of Oklahoma, 2002
2. D.Sc. Tectono-physics, Institute of Geology, State Seismological Bureau, China, 1993
3. M.S. Engineering Geology, Southwest Jiaotong University, China, 1987
4. B.S. Engineering Geology, Southwest Jiaotong University, China, 1984

Experience

1. 8/2011-present: *Associate Professor,* Petroleum & Geological Engineering, University of North Dakota, Grand Forks, ND
2. 08/2005-08/2011: *Assistant Professor,* Geology and Geological Engineering, University of North Dakota, Grand Forks, ND
3. 09/2002-08/2005: *Res. Associate* (09/02-06/03) and *Res. Scientist* (06/03-08/05), Petroleum Recovery Res. Center, New Mexico Institute of Mining and Technology, Socorro, NM
4. 08/1996-05/2002: *GRA,* Rock Mechanics Institute, School of Petroleum & Geological Engineering, University of Oklahoma, Norman, OK
5. 02/1989-08/1996: *Asso. Res. Prof.* (07/93-08/96), *Asst. Res. Prof.* (07/93-12/95), and *GRA* (02/89-07/93), Institute of Geology, State Seismological Bureau, Beijing, China
6. 09/1984-02/1989: *Teaching Assistant* (02/87-02/89, fulltime entry level faculty) and *GRA* (09/84-02/87), Engineering Geology, Southwest Jiaotong University, Sichuan, China

Recent Related Projects

1. PI: Geomechanical Study of Bakken Formation for Improved Oil Recovery, $1M sponsored by US DOE (2008-12).
2. Co-PI: Petroleum Research, Education & Entrepreneurship Center of Excellence, $3M funded by NDDoC, with $8M match from API, IHS Inc., Schlumberger, and UND Alumni Foundation (2009-12).
3. PI: Modeling CO2 Foam Flooding Mechanisms, $127K sponsored by US DOE via Petroleum Recovery Research Center, New Mexico Tech (2006-08).

Selected Publications

1. Pei, P., **Zeng, Z.**, 2012. Estimating Recovery Factor and Cavity Stability of Commercial Scale Underground Coal Gasification Plants, paper ARMA12-308, 46th US Rock Mechanics / Geomech. Symp., Chicago, Illinois. June 24-27, 2012.
2. Pei, P., **Zeng, Z.**, Liu, H., and Ahmed, S., 2012. Preliminary Experimental Study of Surrounding Rock Properties for Underground Coal Gasification in Western North Dakota, paper ARMA12-200, 46th US Rock Mechanics / Geomech. Symp., Chicago, Illinois. June 24-27, 2012.
3. Pei, P., **Zeng, Z.**, and He, J. 2010. Feasibility Study of Underground Coal Gasification Combined with CO_2 Capture and Sequestration in Williston Basin, North Dakota, paper ARMA10-240, Proc.

44th U.S. and 5th U.S.-Canada Rock Mech. Symp., Salt Lake City, Utah. June 27-30, 2010.

4. Pei, P., **Zeng, Z.**, and He, J., 2011. Characterization of the Harmon Lignite for Underground Coal Gasification, in process, Proc. of the 24th Annual International Pittsburgh Coal Conference, Pittsburgh, Pennsylvania. September 12 - 15, 2011.
5. **Zeng, Z.**, and Pei, P. 2010. Underground Coal Gasification (UCG) with CO_2 Enhanced Oil Recovery (EOR) in Western North Dakota, paper abstract No. 18160, presented at The 2010 Geological Society of America Annual Meeting, Denver, Colorado. October 31-November 1, 2010.
6. **Zeng, Z.**, and Pei, P. 2009. Underground Coal Gasification Process Coupled with On-site Carbon Storage and Enhanced Hydrocarbon Recovery in North Dakota, Williston Basin, paper abstract No. 166-3, presented at The 2009 Geological Society of America Annual Meeting, Portland, Oregon. October 18-21, 2009.
7. *Jabbari, H.*, **Zeng, Z.** and *Ostadhassan, M.* Impact of In-Situ Stress Change on Fracture Conductivity in Naturally Fractured Reservoirs: Bakken Case Study. Paper ARMA11-239, *Proc. 45th US Rock Mech. / Geomech. Symp.* held in San Francisco, CA, June 26–29, 2011. 8 p.
8. *Ostadhassan, M.*, **Zeng, Z.** and *Jabbari, H.* Using Advance Acoustic Data to Determine Stress State Around Wellbore, paper ARMA 11-319, *Proc. 45th US Rock Mech. / Geomech. Symp.* held in San Francisco, CA, June 26–29, 2011. 7 p.
9. *Fa, L.*, **Zeng, Z.** and *Liu, H.* A new device for measuring in-situ stresses by using acoustic emissions in rocks, paper ARMA10-160, Proc. 44th U.S. and 5th U.S.-Canada Rock Mech. Symp., Salt Lake City, UT, June 27-30, 2010. 7 p.
10. *Jabbari, H.*, Kharrat, R., **Zeng, Z.**, Mostafavi, V.R., and Emamzadeh, A. Modeling the Toe-to-Heel Air Injection Process by Introducing a New Method of Type-Curve Match, paper SPE 132515, *Proc. the Western North America Regional Meeting* held in Anaheim, California, USA, 26–30 May, 2010. 14 p.
11. *Jiang, A.*, **Zeng, Z.**, *Zhou, X.* and Han, Y. 2009. A strain-softening model for drilling-induced damage on boreholes in Williston Basin, paper ARMA09-026, *Proc. 43rd U.S. and 4th U.S.-Canada Rock Mech. Symp.*, Ashville, NC, USA. June 28-July 1. 8 p.
12. **Zeng, Z.** and *Jiang, A.* 2009. Geomechanical Study of Bakken Formation for Improved Oil Recovery, SINOROCK2009 paper No. 341, *Proc. ISRM Int. Symp. Rock Mech.*, Hong Kong, China. May 19-22. 5 p.
13. *Zhou, X.*, **Zeng, Z.**, *Belobraydic, M.*, and Han, Y. 2008. Geomechanical stability assessment of Williston Basin formations for petroleum production and CO2 sequestration. Paper ARMA08-211, *Proc. 42nd US Rock Mech. and 2nd U.S.-Canada Rock Mech. Symp.*, San Francisco, California, USA. June 29-July 2. 9 p.
14. **Zeng, Z.** and Grigg, R. B., 2006: A Criterion for Non-Darcy Flow in Porous Media, *Transport in Porous Media, 63, pp. 57-69.*
15. **Zeng, Z.**, Grigg, R.B. and Bai, B., 2006: Experimental Development of Adsorption and Desorption Kinetics of a CO_2-foaming Surfactant onto Berea Sandstone, paper SPE 103117, *Proc. 2006 SPE Annual Technical Conference*, San Antonio, Texas, USA, September 24-27. 8 p.
16. **Zeng, Z.**, Roegiers, J-C. and Grigg, R. B., 2004: "Experimental Determination of Geomechanical and Petrophysical Properties of Jackfork Sandstone – A Tight Gas Formation," paper ARMA/NARMS04-562, *Proc. 6^{th} North America Rock Mechanics Symposium*, Houston, Texas, USA, June 5 – 9. 9 p.

CV of Steven A. Benson, Co- PI

STEVEN A. BENSON
Chair, Petroleum Engineering Program and Director, Institute for Energy Studies
Professor of Chemical Engineering

Areas of Expertise

Dr. Benson's principal areas of interest and expertise include development and management of complex multidisciplinary programs that are focused on solving environmental and energy problems, associated with the development and utilization of fuel resources. These programs include: 1) technologies to improve the performance of fuel resource recovery, refining, conversion and environmental control systems; 2) transformations and control of trace elements in combustion and gasification systems; 3) carbon dioxide separation and capture technologies, 4) advanced analytical techniques to measure the chemical and physical transformations of inorganic species in gases; 5) computer-based models to predict the emissions and fate of pollutants from combustion and gasification systems; 6) advanced materials for power systems; 7) impacts of power system emissions on the environment; 8) national and international conferences and training programs; and 8) state and national environmental policy.

Education and Training

Minnesota State University	Chemistry	B.S. 1977
Pennsylvania State University	Fuel Science	Ph.D. 1987

Research and Professional Experience

2010 – present Director/Chair, Petroleum Engineering and Institute for Energy Studies – coordinate energy related education and research activities that involve faculty, research staff, and student.

2008 – present Professor, University of North Dakota -- Dr. Benson is responsible for teaching courses on energy production and associated environmental issues. Dr. Benson conducts research, development, and demonstration projects aimed at solving environmental, efficiency, and reliability problems associated with the utilization of fuel resources in refining/combustion/gasification systems that include: petroleum coke utilization, transformations of fuel impurities; carbon dioxide separation and capture technologies, advanced analytical techniques, and computer based models.

1999 – 2008 Senior Research Manager/Advisor, Energy & Environmental Research Center, University of North Dakota (EERC, UND) -- Dr. Benson is responsible for leading a group of about 30 highly specialized group of chemical, mechanical and civil engineers along with scientists whose aim is to develop and conduct projects and programs on combustion and gasification system performance, environmental control systems, the fate of pollutants, computer modeling, and health issues for clients worldwide.

1994 – 1999 Associate Director for Research, EERC, UND -- Dr. Benson was responsible for the direction and management of programs related to integrated energy and environmental systems development. Dr. Benson led a team of over 45 scientists, engineers, and technicians.

1991 – Present President, Microbeam Technologies Incorporated (MTI) -- Dr. Benson is the founders of MTI whose mission is to conduct service analysis of materials using automated methods. MTI began operations in 1992 and has conducted over 1300 projects for industry, government, and research organizations.

1989 – 1991 Assistant Professor of Geological Engineering, Department of Geology and Geological Engineering, UND -- Dr. Benson was responsible for teaching courses on fuel geochemistry, fuel/crude behavior in refining, combustion and gasification systems, and analytical methods of materials analysis.

1986 – 1994 Senior Research Manager, Fuels and Materials Science, EERC, UND -- Dr. Benson was responsible for management and supervision of research on the behavior of inorganic constituents in fuels in combustion and gasification.

1984 – 1986 Graduate Research Assistant, Fuel Science Program, Department of Materials Science and Engineering, The Pennsylvania State University, Mr. Benson took course work in fuel science, chemical engineering (at UND), and ceramic science and performed independent research leading to a Ph.D. in Fuel Science.

1983 – 1984 Research Supervisor, Distribution of Inorganics and Geochemistry, Coal Science Division, UND Energy Research Center

1977 – 1983 Research Chemist, U.S. Department of Energy Grand Forks Energy Technology Center, Grand Forks, North Dakota

Selected Related Publications (Author and co-author of over 200 publications)

1. Benson, S.A. and Sondreal, E.A., Gasification of Lignites of North America, North Dakota Industrial Commission, 2010.
2. Pavlish, J.H., Laumb, J.D., and Benson S.A., Eds, Air Quality VI: Mercury, Trace Elements, SO_3, Particulate Matter, & Greenhouse Gases, Special Issue of Fuel Process. Technol.; Elsevier Science Publishers: Amsterdam, 2009, Vol. 90, No. 11, 1327-1434.
3. Van Dyk, J.C., Benson, S.A., Laumb, M.L., and Waanders, B., Coal and coal ash characteristics to understand mineral transformations and slag formation, Fuel, Volume 88, Issue 6, 2009, Pages 1057-1063.
4. Benson, S.A., Pavlish, J.H., Holmes, M.J., Crocker, C.R., Galbreath, K.C., and Zhaung, Y., Mercury control testing in a pulverized lignite-fired system, Fuel Processing Technology, Volume 90, Issue 11, 2009, Pages 1378-1387.
5. Jones, M.L., Pavlish, B.M., Laumb, J.D., Lentz, N.B, and Benson, S.A., Fuel derived impurities impacts on CO_2 separation and capture technologies, *Prepr. Pap.—Am. Chem. Soc., Div. Fuel Chem.* 2008, *53* (2), 812-813.

6. Stanislowski, J.J., Laumb, J.D., Swanson, M.L., and Benson, S.A., Impact on lignite impurities on gasification and gas clean up, *Prepr. Pap.—Am. Chem. Soc., Div. Fuel Chem.* 2008, *53* (2), 810-812.
7. Benson, S.A.; Holmes, M.J. Coproducing Electricity, Hydrogen, and Synthetic Fuels from Lignite with Carbon Dioxide Capture and Utilization. Presented at the Energy Generation Conference, Bismarck, ND, Jan 31 – Feb 1, 2007.
8. Jones, M.L.; Stanislowski, J.J.; Benson, S.A.; and Laumb, J.D. Gasification of Lignites to Produce Liquid Fuels, Hydrogen, and Power, Twenty-Fourth International Pittsburgh Coal Conference, Johannesburg, South Africa, Sep 10-14, 2007.
9. Ma, Z.; Iman, F.; Lu, P.; Sears, R.; Vasquez, E.; Yan, L.; Kong, L.; Rokanuzzaman, A.S.; McCollor, D.P.; Benson, S.A. A comprehensive slagging and fouling prediction tool for coal-fired boilers and its validation/application, *Fuel Process. Technol*, 2007, 88, 1035–1043.
10. Steadman, E.; Benson, S. Gasification, CO_2 Capture, and Sequestration. In *Proceedings of the Symposium on Western Fuels: 20th International Conference on Lignite, Brown, and Subbituminous Coals Workshops*; Denver, CO, Oct 23, 2006.

Synergistic Activities

- Lignite Energy Council, Distinguished Service Award, Research & Development, 1997; College of Earth and Mineral Science Alumni Achievement Award, Pennsylvania State University, 2002; Lignite Energy Council, Distinguished Service Award, Research & Development, 2003; Lignite Energy Council, Distinguished Service Award, Government Action Program (Regulatory), 2005; Lignite Energy Council, Distinguished Service Award, Research & Development, 2008.
- Provided testimony to the United States Senate Committee on the Environment and Public Works – Mercury emissions control at coal fired power plants - 2008 and 2005.

CV of Co-PI Scott Korom

Scott F. Korom, Ph.D., P.E., Associate Professor of Geological Engineering

Educational Background

Ph.D. Civil and Environmental Engineering, Utah State University, 1992.

M.S. Civil Engineering, University of Akron, 1984.

B.S. Civil Engineering, University of Akron, 1982.

Professional Experience

Associate Professor of Geological Engineering, U. of North Dakota, 2000-present.

Assistant Professor of Geological Engineering, U. of North Dakota, 1994-2000.

Other Related Experience

Postdoctoral Research Fellow, Oak Ridge Associated Universities, Savannah River Site, Aiken, SC, 1992-1994. *Responsibilities*: Experimentally and numerically tested the use of anionic groundwater tracers to determine physical and chemical properties of contaminated aquifers.

Research Engineer, Utah State University, 1991-1992. *Responsibilities*: Groundwater hydrologist for a research project evaluating the effectiveness of bioremediation of a U.S. EPA Superfund site in Libby, MT. This was the first Superfund site for which bioremediation of groundwater was specified in the record of decision.

Honors, Awards, and Selected Grants

Authored or co-authored grants and contracts awarded for over $1,000,000, including the following:

- Aquifer Assessment in Peru: Fate and Transport of Nitrate and Selenium. Ground Water International, Lima, Peru, $9,999, 10/06-8/07.
- Collaborative Research on In Situ Denitrification & Glyphosate Transformation in Ground Water: NAWQA Eastern Iowa Basins, USGS, $91,988, 8/06-7/09, with P. Capel.
- Coupling of organic carbon and sulfide to denitrification, U.S. Department of Agriculture, $47,810, 9/95-12/98, with P. Gerla.
- Effects of iron bacteria on subsurface tile drains: Influence on hydraulic efficiency and nutrient transport, US Bureau of Reclamation, $206,390 (UND portion: $88,500), 10/2007 to 12/2009, with F. Casey (NDSU) and A. Schlag (formally of USBR).

Identified twice as one of UND's faculty "stars" by one or more Presidential Scholars, letters from President Kupchella, 1/4/08 and 1/9/06.

Selected as an "Expert of International Standing," Australian Research Council College of Experts, 4/2006.

UND Summer Graduate Research Professorship, 5/06 to 7/06.

Selected as a "Short List" candidate for the *Ad Hoc* Integrated Nitrogen Research Committee of the US EPA Science Advisory Board, fall 2005.

Cited for Excellence in Refereeing, letter dated 3/2/2010 by Mary P. Anderson, Editor in Chief, *Ground Water*.

North Dakota Spirit Faculty Achievement Award, 2011.

Scientific and Professional Societies

American Geophysical Union
American Society of Civil Engineers
National Ground Water Association
Tau Beta Pi National Engineering Honor Society

Selected Publications

Korom, S. F., S. Sarikelle, and A. L. Simon, Design of hydraulic jump chambers, *Journal of Irrigation and Drainage Engineering*, ASCE, *116*(2), 143-153, 1990.

Korom, S.F., Comment on "Modeling of multicomponent transport with microbial transformation in groundwater: The Fuhrberg case" by E. O. Frind et al., *Water Resources Research, 27*(12), 3271-3274, 1991.

Korom, S.F., Natural denitrification in the saturated zone: A review, *Water Resources Research, 28*(6), 1657-1668, 1992.

Korom, S.F., and R.W. Jeppson, Nitrate contamination from dairy lagoons constructed in coarse alluvial deposits, *Journal of Environmental Quality*, *23*(5), 973-976, 1994.

Korom, S.F., and R.W. Jeppson, Nutrient leaching from alfalfa irrigated with municipal wastewater, *Journal of Environmental Engineering*, ASCE, *120*(5), 1067-1081, 1994.

Korom, S.F., M.J. McFarland, and R. Sims, Reduced sediments: A factor in the design of subsurface oxidant delivery systems, *Ground Water Monitoring and Remediation, 16*(1), 100-105, 1996.

Seaman, J.C., P.M. Bertsch, S.F. Korom, and W.P. Miller, Physicochemical controls on non-conservative anion migration in coarse-textured alluvial sediments, *Ground Water*, *34*(5), 778-783, 1996.

Korom, S.F., An adsorption isotherm for bromide, *Water Resources Research, 36*(7), 1969-1974, 2000.

James, L. D., and S. F. Korom, Lessons from Grand Forks: Planning structural flood control measures, *Natural Hazards Review*, ASCE, *2*(1), 22-32, 2001.

James, L. D., and S. F. Korom, Lessons from Grand Forks: Planning nonstructural flood control measures, *Natural Hazards Review*, ASCE, *2*(4), 182-192, 2001.

Korom, S. F., K. F. Bekker, and O. J. Helweg, Influence of pump intake location on well efficiency, *Journal of Hydrologic Engineering*, ASCE, *8*(4), 197-203, 2003.

Korom, S.F., A.J. Schlag, W.M. Schuh, and A.K. Schlag, In situ mesocosms: Denitrification in the Elk Valley Aquifer, *Ground Water Monitoring and Remediation*, *25*(1), 79-89, 2005.

Korom, S.F., and E.J. Dodak. Numerical study of bromide as a tracer for aquifer macrodispersivity tests: Comparing conservative behavior to mildly nonlinear adsorption, *Journal of Hydrologic Engineering*, 14(12), 1383-1389, 2009.

Korom, S.F. Graphical solutions for hillslopes: Discharge, head and velocity diagrams, *Journal of Irrigation and Drainage Engineering*, *136*(8), 563-566, 2010.

Gerla, P.J., M.U. Sharif, and S.F. Korom. Geochemical processes controlling the spatial distribution of selenium in soil and water, west central South Dakota, USA, *Environmental Earth Sciences,62*(7), 1551-1560, 2011.

Korom, S.F., W.M. Schuh, T.Tesfay, and E.J. Spencer. Aquifer denitrification and in situ mesocoms: Modeling electron donor contributions and measuring rates, *Journal of Hydrology, 432-433*, 112-126, 2012.

Selected Institutional/Professional Service

Director, Geological Engineering, U. of North Dakota, 2009-2011.

Director, Graduate Programs in Environmental Engineering, U. of North Dakota, 2005-2007.

Director, Water Resources Research Laboratory, U. of North Dakota, 1998-2002.

Peer Referee for over 10 journals and for over 10 regional, national, or international research organizations.

Professional Registration

Licensed Professional Engineer, North Dakota, 1995-present.

Appendix 2: Preliminary work on UCG and other related topics

1. Pei, P., Zeng, Z., 2012. Estimating Recovery Factor and Cavity Stability of Commercial Scale Underground Coal Gasification Plants, paper ARMA12-308, 46th US Rock Mechanics / Geomech. Symp., Chicago, Illinois. June 24-27, 2012.
2. Pei, P., Zeng, Z., Liu, H., and Ahmed, S., 2012. Preliminary Experimental Study of Surrounding Rock Properties for Underground Coal Gasification in Western North Dakota, paper ARMA12-200, 46th US Rock Mechanics / Geomech. Symp., Chicago, Illinois. June 24-27, 2012.
3. Pei, P., Zeng, Z., and He, J. 2010. Feasibility Study of Underground Coal Gasification Combined with CO_2 Capture and Sequestration in Williston Basin, North Dakota, paper ARMA10-240, Proc. 44th U.S. and 5th U.S.-Canada Rock Mech. Symp., Salt Lake City, Utah. June 27-30, 2010.
4. Pei, P., Zeng, Z., and He, J., 2011. Characterization of the Harmon Lignite for Underground Coal Gasification, in process, Proc. of the 24th Annual International Pittsburgh Coal Conference, Pittsburgh, Pennsylvania. September 12 - 15, 2011.
5. Zeng, Z., and Pei, P. 2010. Underground Coal Gasification (UCG) with CO_2 Enhanced Oil Recovery (EOR) in Western North Dakota, paper abstract No. 18160, presented at The 2010 Geological Society of America Annual Meeting, Denver, Colorado. October 31-November 1, 2010.
6. Zeng, Z., and Pei, P. 2009. Underground Coal Gasification Process Coupled with On-site Carbon Storage and Enhanced Hydrocarbon Recovery in North Dakota, Williston Basin, paper abstract No. 166-3, presented at The 2009 Geological Society of America Annual Meeting, Portland, Oregon. October 18-21, 2009.
7. Pei, P., and Kulkarni, M. 2008. A Model for Analysis of Integrated Gasification Combined Cycle (IGCC) with Carbon Dioxide Capture, paper POWER2008-60124, Proc. of ASME Power 2008, Orlando, Florida, July 22-24.
8. Pei P, and Kulkarni, M. 2008. Modeling of Ultra Superheated Steam Gasification in Integrated Gasification Combined Cycle Power Plant with Carbon Dioxide Capture, paper ES2008-54325, Proc. of Energy Sustainability 2008, Jacksonville, Florida, August 10–14.
9. Jabbari, H., Kharrat, R., Zeng, Z., Mostafavi, V.R., and Emamzadeh, A. 2010. Modeling the Toe-to-Heel Air Injection Process by Introducing a New Method of Type-Curve Match, paper SPE 132515, Proc. the Western North America Regional Meeting held in Anaheim, California, USA, 26–30 May.
10. Fa, L., Zeng, Z., and Liu, H. 2010. A New device for Measuring in-situ Stresses by Using Acoustic Emissions in Rocks, paper ARMA10-160, Proc. 44th U.S. and 5th U.S.-Canada Rock Mech. Symp., Salt Lake City, UT, USA. June 27-30.
11. Jiang, A., Zeng, Z., Zhou, X. and Han, Y. 2009. A Strain-softening Model for Drilling-induced Damage on Boreholes in Williston Basin, paper ARMA09-026, Proc. 43rd U.S. and 4th U.S.-Canada Rock Mech. Symp., Ashville, NC, USA. June 28-July 1.

12. Zhou, X., Zeng, Z., and Liu, H. 2010. Laboratory Testing on Pierre shale for CO_2 Sequestration under Clayey Caprock, paper ARMA10-107, Proc. 44th U.S. and 5th U.S.-Canada Rock Mech. Symp., Salt Lake City, UT, USA. June 27-30.

Appendix 3: Quotation on well drilling

INTERSTATE DRILLING SERVICES, LLP

1575 NORTH 73RD STREET
GRAND FORKS, ND 58203

Quotation

DATE	Quotation No.
2/28/2012	2012059

Client
University of North Dakota Grand Forks, ND

PROJECT
Coal Coring

ITEM	DESCRIPTION	QTY	COST	TOTAL
Mobilization	Mob/Demob	1	5,500.00	5,500.00
Drilling	Drilling of Overburden 900-1200 total feet (per hr)	15	350.00	5,250.00
Coring	Wireline Coring 300 to 500 feet (per hr)	50	380.00	19,000.00
Expenses	Motel and Meals (per day)	7	450.00	3,150.00
Materials	Drilling Materials	1	2,500.00	2,500.00
			Total	$35,400.00

Appendix 4: Letter of support on matching fund

Appendix 5. Budget for three drill core locations

Total budget

BUDGET OUTLINE	F&A =	0.38	
DESCRIPTION	**YEAR 1**	**YEAR 2**	**TOTAL**
SALARIES - REGULAR	34,631	36,363	70,994
SALARIES - OTHER	45,600	47,400	93,000
SALARIES - FACULTY	37,505	39,380	76,884
FRINGE BENEFITS	21,722	22,503	44,225
			0
TOTAL PERSONNEL	139,458	145,645	285,103
			0
TRAVEL	8,000	8,000	16,000
COMMUNICATIONS-PHONE	0	0	0
COMMUNICATIONS-POSTAGE	200	200	400
INSURANCE	0	0	0
RENTS/LEASES-EQUIPMENT & OTHER	200	200	400
RENTS/LEASES-BUILDING/LAND	0	0	0
OFFICE SUPPLIES	200	200	400
PRINTING-COPIES, DUPLICATING	200	200	400
REPAIRS	0	0	0
UTILITIES	0	0	0
SUPPLIES-IT SOFTWARE	200	200	400
SUPPLY/MATERIALS-PROFESSIONAL	200	200	400
SUPPLIES-MISCELLANEOUS	2,000	2,000	4,000
IT EQUIPMENT <$5,000	0	0	0
OTHER EQUIPMENT <$5,000	1,000	0	1,000
FEES-OPERATING FEES & SERVICES	0	0	0
FEES-PROFESSIONAL FEES & SERVICES	4,110	4,110	8,220
FEES-SUBCONTRACTS (see Note 1 below)	106,200	0	106,200
PROFESSIONAL DEVELOPMENT	200	200	400
FOOD AND CLOTHING	500	500	1,000
WAIVERS/SCHOLARSHPS/FELLOWSHPS	30,000	30,000	60,000
			0
TOTAL OPERATING	153,210	46,010	199,220
			0
EQUIPMENT >$5,000	50,000	0	50,000
IT EQUIPMENT >$5,000	0	0	0
			0
TOTAL EQUIPMENT	50,000	0	50,000
			0
TOTAL DIRECT COST	342,668	191,655	534,323
			0
F&A (INDIRECT COST) *	68,958	61,429	130,387
			0
TOTAL COST	**411,625**	**253,085**	**664,710**

Yearly budget

Year 1				
Item	Rate($)	Quantity	NDIC	Industry
Personnel				
Salary				
Faculty1(PI)	8,904.00	2.00	8,904	8,904
Faculty2(co-PI)	12,086.00	0.75	4,532	4,532
Faculty3	10,632.00	1.00	5,316	5,316
Staff_Lab Technician	3,549.00	9.00	15,971	15,971
Staff_Administrative Support	3,587.00	0.75	1,345	1,345
Other_Graduate Research Assistant X 2	1,650.00	12.00	19,800	19,800
Other_Undergrad Research Assistant	500.00	12.00	3,000	3,000
Fringe benefits				
Faculty (PI)	0.20		1,781	1,781
Faculty2(co-PI)	0.20		906	906
Faculty3	0.20		1,063	1,063
Lab technician	0.35		5,590	5,590
Administrative Support	0.35		471	471
GRA x 2	750.00	2.00	750	750
URA	0.10	1.00	300	300
Total Personnel			69,729	69,729
Operational				
TRAVEL	2,000.00	4.00	4,000	4,000
COMMUNICATIONS-PHONE				
COMMUNICATIONS-POSTAGE	200.00	1.00	100	100
INSURANCE				
RENTS/LEASES-EQUIPMENT & OTHER	200.00	1.00	100	100
RENTS/LEASES-BUILDING/LAND				
OFFICE SUPPLIES	200.00	1.00	100	100
PRINTING-COPIES, DUPLICATING	200.00	1.00	100	100
REPAIRS				
UTILITIES				
SUPPLIES-IT SOFTWARE	200.00	1.00	100	100
SUPPLY/MATERIALS-PROFESSIONAL	200.00	1.00	100	100
SUPPLIES-MISCELLANEOUS	1,000.00	2.00	1,000	1,000
IT EQUIPMENT <$5,000	0.00	0.00	0	0
OTHER EQUIPMENT <$5,000	1,000.00	1.00	500	500
FEES-OPERATING FEES & SERVICES				
FEES-PROFESSIONAL FEES & SERVICES	4,110.00	1.00	2,055	2,055
FEES-SUBCONTRACTS	35,400.00	3.00	53,100	53,100
PROFESSIONAL DEVELOPMENT	200.00	1.00	100	100
FOOD AND CLOTHING	500.00	1.00	250	250
WAIVERS/SCHOLARSHPS/FELLOWSHPS	15,000.00	2.00	15,000	15,000
TOTAL OPERATING			76,605	76,605
EQUIPMENT >$5,000	50,000.00	1.00	25,000	25,000
IT EQUIPMENT >$5,000				
TOTAL EQUIPMENT			25,000	25,000
TOTAL DIRECT COST			171,334	171,334
F&A (INDIRECT COST) *			34,479	34,479
TOTAL COST			205,813	205,813
Y1 Total (State + Industry)				**411,625**

Year 2

Item	Rate($)	Quantity	NDIC	Industry
Personnel				
Salary				
Faculty (PI)	9,349.20	2.00	9,349	9,349
Faculty2(co-PI)	12,690.30	0.75	4,759	4,759
Faculty3	11,163.60	1.00	5,582	5,582
Staff_Lab Technician	3,726.45	9.00	16,769	16,769
Staff_Administrative Support	3,766.35	0.75	1,412	1,412
Other_Graduate Research Assistant X 2	1,725.00	12.00	20,700	20,700
other_Undergrad Research Assistant	500.00	12.00	3,000	3,000
Fringe benefits				
Faculty (PI)	0.20		1,870	1,870
Faculty2(co-PI)	0.20		952	952
Faculty3	0.20		1,116	1,116
Lab technician	0.35		5,869	5,869
Administrative Support	0.35		494	494
GRA x 2	650.00	2.00	650	650
URA	0.10	1.00	300	300
Total Personnel			72,823	72,823
Operational				
TRAVEL	2,000.00	4.00	4,000	4,000
COMMUNICATIONS-PHONE				
COMMUNICATIONS-POSTAGE	200.00	1.00	100	100
INSURANCE				
RENTS/LEASES-EQUIPMENT & OTHER	200.00	1.00	100	100
RENTS/LEASES-BUILDING/LAND				
OFFICE SUPPLIES	200.00	1.00	100	100
PRINTING-COPIES, DUPLICATING	200.00	1.00	100	100
UTILITIES				
SUPPLIES-IT SOFTWARE	200.00	1.00	100	100
SUPPLY/MATERIALS-PROFESSIONAL	200.00	1.00	100	100
SUPPLIES-MISCELLANEOUS	1,000.00	2.00	1,000	1,000
IT EQUIPMENT <$5,000				
OTHER EQUIPMENT <$5,000				
FEES-OPERATING FEES & SERVICES				
FEES-PROFESSIONAL FEES & SERVICES	4,110.00	1.00	2,055	2,055
FEES-SUBCONTRACTS				
PROFESSIONAL DEVELOPMENT	200.00	1.00	100.00	100.00
FOOD AND CLOTHING	500.00	1.00	250.00	250.00
WAIVERS/SCHOLARSHPS/FELLOWSHPS	15,000.00	2.00	15,000	15,000
TOTAL OPERATING			23,005	23,005
EQUIPMENT >$5,000				
IT EQUIPMENT >$5,000				
TOTAL EQUIPMENT				
TOTAL DIRECT COST			95,828	95,828
F&A (INDIRECT COST)			30,715	30,715
TOTAL COST			126,542	126,542
Y2 Total (State + Industry)				**253,085**