**TECHNICAL REVIEWERS' COMMENTS**

**LRC-LXXIII(73)-C:**
**"Geomechanical Study of Harmon Lignite and Surrounding Rocks for Underground Coal Gasification in Western North Dakota"**
Submitted by: University of North Dakota Institute for Energy Studies;
Request for: $242,729; Total Project Costs: $485,712;
Principal Investigator: Zhengwen Zeng, Ph.D.;
Co-Principal Investigators: Steven A. Benson, Ph.D. and Scott F. Korom, Ph.D.
Project Duration: Two Years.

## 1. OBJECTIVES

The objectives or goals of the proposed project with respect to clarity and consistency with Industrial Commission/Lignite Research Council goals are: 1 - very unclear; 2 - unclear; 3 - clear; 4 - very clear; or 5 - exceptionally clear.

**Reviewer 12-07 (Rating: 2)**

The goals should have addressed the commercial aspects of UCG more. As written, I'm not sure whether this is just a research project or a research project slanted toward commercialization. Given the goals of the Commission and the industry participation, it should be the latter. See my general comments below and in the proposal. For example, the proposal should have included some preliminary calculations regarding the area needed for a small commercial operation and related that to size of the "model UCG site" in the proposal. The proposal wording and scope should be changed to a "potential model UCG resource" rather than a site. I inferred from the proposal that the model site might be perhaps a quarter of a section which is of no commercial development value.

**Reviewer 12-08 (Rating: 4)**

The proposed project meets the criteria set out by the "Statutory Goals & Purposes" of the North Dakota Industrial Commission (NDIC) as well as the requirements of "development projects".

**Reviewer 12-09 (Rating: 5)**

The central objective of the proposed project is to determine the feasibility of using underground coal gasification (UCG) to access currently un-economic lignite resources in North Dakota. The proposed field characterization and laboratory testing is precisely the groundwork necessary to make such an assessment. If successful, the work may demonstrate the North Dakota lignite resources can be accessed in an economic and environmentally-responsible manner, and therefore this proposal is strongly in line with the NDIC/LRC's stated goal of "promote economic, efficient, and clean use of lignite."

## 2. ACHIEVABILITY

With the approach suggested and time and budget available, the objectives are: 1 - not achievable; 2 - possibly achievable; 3 - likely achievable; 4 - most likely achievable; or 5 - certainly achievable.

**Reviewer 12-07 (Rating: 3)**

My main questions in this regard are-- (1) if the drilling schedule slips due to climate, previous driller commitments or lack of drilling personnel (which often happens), what impact this would have on the project schedule and (2) what are the impacts and contingency plan if the equipment modifications to the core tester fail to materialize.

**Reviewer 12-08 (Rating: 3)**

The proposal is likely ambitious given the budget and scope:

(a) **Potentially high cost of drilling and coring wells:** The requirement to drill and sample three test wells by the industrial partner is highly advisable. However, it is not clear from the proposal if the cost estimate from the drilling contractor in Appendix 3 ($35,400) is for drilling/coring all three wells or one single well. If this quote is for one well only, then drilling will become a significant portion of the overall $486K budget.

(b) **Computer modeling/simulation:** The current status of the modeling/simulation initiatives is not evident from the proposal; if the models are yet to be developed, a two year timeline could be aggressive. The time frame (3 quarters) allocated to the modeling effort seems low.

**Reviewer 12-09 (Rating: 5)**

It is my view that the proposed work has a high probability of achieving its objectives in the proposed two-year time frame. The scope of work is well focused. All of the sampling, testing and analysis methods are more-or-less standard, with a low risk for undue time delays. Also, almost all of the necessary equipment and resources are already in place using existing facilities at UND. The assembled team is well qualified for the work, and already has the necessary background in the UCG process.

Only two (minor) concerns may lead to project delays. The proposal does involve field drilling work, for which the university will subcontract to a company. Second, they propose to install one new piece of equipment in their laboratory: a high-temperature loading cell. Delays in either case should not be of sufficient magnitude, however, to jeopardize the objectives of the work.

## 3. <u>METHODOLOGY</u>

The quality of the methodology displayed in the proposal is: 1 - well below average; 2 - below average; 3 - average; 4 - above average; or 5 - well above average.

**Reviewer 12-07 (Rating: 3)**

The methodology proposed in this proposal is a reliable methodology which has been used many times in previous UCG studies. The proposers do add a new twist to the rock mechanics studies by conducting them at elevated temperatures.

**Reviewer 12-08 (Rating: 4)**

Tasks #1 – the sources of public information are well defined. The proposal to conduct preliminary hydrogeological modeling is very good for initial screening. However, other site selection criteria are not defined; apparently the industry sponsor will provide the screening criteria. One would expect that the project proponents might be in the best position to suggest a comprehensive list of screening criteria?

Task #2 – this is well defined; however, the specific samples to be taken from the coal seams during drilling e.g. canister core samples, etc. need to be better defined. As indicated in Item #2 above, drilling costs could be a significant portion of the overall project budget.

Task #3 – this is very well defined, and clearly a strength of the proponent group. The use of the data generated in this task would support the proposed mechanical strength assessment of the coal seam.

Task #4 – while the overall modeling/simulation steps described are reasonable, the development of an integrated gasification, structural integrity and hydrogeological performance of the UCG cavity will likely be a challenge in the 2 year time frame; notwithstanding the comment in Item #2 on the current status of the computer modeling efforts.

It is strongly recommended that the modeling/simulation initiative start at the project onset and be given more time than the mid-project start and three quarter duration currently assigned. (Table 2, Page 24).

**Reviewer 12-09 (Rating: 5)**
The proposed methodology is both sophisticated and sufficient to answer the underlying UCG feasibility question. The work consists of an appropriate mix of field characterization, laboratory testing, and numerical modeling. The proposed measurements will give a sufficiently complete picture of the local lignite resources in terms of their thermal, hydrologic, and mechanical paper.

## 4. CONTRIBUTION

The scientific and/or technical contribution of the proposed work to specifically address Industrial Commission/LRC goals will likely be: 1 - extremely small; 2 - small; 3 - significant; 4 - very significant; or 5 - extremely significant.

**Reviewer 12-07 (Rating: 2)**

The contribution, as the study is proposed now, would be small. If the suggestions proposed below are incorporated, the study would become very significant since, it would provide an initial evaluation of a commercially sized resource. If the 'model UCG resource' evaluation is favorable, it should give industry the incentive to take it one step further and further evaluate the prospect on its own. This would also encourage the state regulatory agencies to implement a policy for permitting UCG. I expect this policy would be very similar to that of Wyoming.

**Reviewer 12-08 (Rating: 3)**

Given that the estimated strippable (surface mineable) coal resource reported for North Dakota is 7 – 50 billion tonnes compared to a total 350 billion tonnes[1], UCG could have a significant impact on utilizing the remaining deeper lignite coal in North Dakota. Furthermore, combined with an adequate $CO_2$ management strategy, UCG could be a low carbon energy source from lignites. North Dakota could have a unique advantage for $CO_2$ use for enhanced oil recovery, which could increase the revenue from a UCG project. Note however that $CO_2$ management is not part of the proposal.

**Reviewer 12-09 (Rating: 5)**

If the proposed work can demonstrate that North Dakota lignite resources can be economically (and responsibly) accessed with UCT, it has the potential to have an extremely significant impact on the local energy sector. As they note in their proposal, only 2% of the state's lignite resources can be accessed by convention surface mining. The appeal of UCG is that it can access deep and unmineable resources without significant surface impacts. It also has several environmental advantages with respect to the composition of the produced syngas stream. The key practical concerns, however, are (1) potential groundwater contamination, (2) unexpected geomechanical collapse, and (3) insufficient syngas quality. The proposed work will provide the necessary data to make an informed analysis of all three aspects.

## 5. AWARENESS

The principal investigator's awareness of current research activity and published literature as evidenced by literature referenced and its interpretation and by the reference to unpublished research related to the proposal is: 1 - very limited; 2 - limited; 3 - adequate; 4 - better than average; or 5 - exceptional.



[1] https://www.dmr.nd.gov/ndgs/Newsletter/NL01W/PDF/lignW01.pdf

**Reviewer 12-07 (Rating: 3)**

The proposers demonstrate that a current review of UCG has been made and quote studies made by others regarding the geomechanics of UCG.

**Reviewer 12-08 (Rating: 3)**

The overall description of the work and activities in the proposal reflects an average understanding of the state of the UCG technology and associated issues with respect to development in North Dakota. Because of the early stage of the UCG technology in general, a higher score would be unusual.

**Reviewer 12-09 (Rating: 4)**

The team appears to be familiar with the current state-of-the-art, and is competent in all relevant aspects. They have participated in ongoing UCG research since at least 2009, and have participated in multiple conferences.

## 6. **BACKGROUND**

The background of the investigator(s) as related to the proposed work is: 1 - very limited; 2 - limited; 3 - adequate; 4 - better than average; or 5 - exceptional.

**Reviewer 12-07 (Rating: 3)**

Scott Korom's participation in the project, with his hydrogeologic background, will be very useful.

**Reviewer 12-08 (Rating: 4)**

UCG requires the close collaboration of process engineers, geologists, hydro geologists and drilling specialists. The principal investigator (PI) and co-PI have the range of backgrounds required to complete such a project.

**Reviewer 12-09 (Rating: 5)**

The assembled team has the necessary competency in all relevant fields: geomechanics, groundwater hydrology, chemical engineering, laboratory and numerical methods. They have already established a track record of work in UCG through their conference publications, and have journal publications in related disciplines that demonstrate high-quality research. Much of this work is focused specifically on North Dakota lignite. They also appear responsive to the input of their industrial partner, who can provide a helpful perspective on the work.

## 7. **PROJECT MANAGEMENT**

The project management plan, including a well-defined milestone chart, schedule, financial plan, and plan for communications among the investigators and subcontractors, if any is: 1 - very inadequate; 2 - inadequate; 3 - adequate; 4 very good; or 5 - exceptionally good.

**Reviewer 12-07 (Rating: 2)**

A simple critical path analysis should be presented to insure that the project activities and schedule has been thought through. There is no indication regarding the disposition of the wells and the budget implications. Will the wells be plugged and abandoned or left open for later hydrological testing or logging. I assume the cost of completing the wells as per state regulations has been included.

I personally prefer to see the tasks broken down into more detail to indicate the amount of thought that was put into the project. It appears that not much thought was put into the wells and the well testing program. Drill stem testing for hydrologic properties for each major overburden formation should be carried out, as well as well logging.

**Reviewer 12-08 (Rating: 2)**

The Management and Schedule described on Pages 22 – 24 needs to be better defined. A second level of task break down with associated timing and cost outlays will be required. Go/no-go decision points need to be incorporated into the overall timeline.

**Reviewer 12-09 (Rating: 4)**

The project management is very good, with an appropriate schedule, milestones, financial plan, and communication plan. The PI and collaborators appear to have experience with project management and execution during previously funded projects.

8. **EQUIPMENT PURCHASE**

The proposed purchase of equipment is: 1 – extremely poorly justified; 2 – poorly justified; 3 – justified; 4 – well justified; or 5 – extremely well justified. (Circle 5 if no equipment is to be purchased.)

**Reviewer 12-07 (Rating: 3)**

The 'word of mouth' pricing of the triaxial load cell is unacceptable however.

**Reviewer 12-08 (Rating: 2)**

There is no quote for the instrument proposed (high temperature loading cell). As well, it is not clear what the data will be used for during the modeling/simulation work.

**Reviewer 12-09 (Rating: 5)**

The proposed project includes equipment purchases associated with developing a high-temperature triaxial testing apparatus ($25k). This purchase is extremely well justified, as it will allow the team to assess the potential degradation of mechanical properties in the heated zone near the combustion cavity. It is often hypothesized that this degradation will have a direct impact on the cavity growth rate. This equipment will therefore provide a rare capability and allow the team to answer highly relevant questions about thermo-mechanical behavior.

9. **FACILITIES**

The facilities and equipment available and to be purchased for the proposed research are: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – notably good; or 5 – exceptionally good.

**Reviewer 12-07 (Rating: 3**)

An assumption on my part.

**Reviewer 12-08 (Rating: 4)**

The proponents have significant existing test equipment and modeling/simulation software (Page 19 and 20) to support the geo-mechanical evaluation of the core samples taken from the drilling program. The principal investigator has evaluated UCG since 2009 and has a technical group established to support the work.

**Reviewer 12-09 (Rating: 5)**

The provided specifications for existing laboratory equipment are quite good and entirely sufficient for the intended tests. If a combined thermal/triaxial capability is developed, the laboratory will have an exceptional capability that will set it apart from most existing facilities (see comments to question 8).

10. **BUDGET**

The proposed budget "value"[2] relative to the outlined work and the financial commitment from other sources[3] is of: 1 - very low value; 2 - low value; 3 - average value; 4 - high value; or 5 very high value.

**Reviewer 12-07 (Rating: 2)**

As is, the study is of low value. See the above comments regarding increasing the value.

**Reviewer 12-08 (Rating: 4)**

Given the scope proposed (which may be ambitious as noted in Item 2 above) this is good value for the money requested from the NDIC. The key will be to ensure that the stated scope is delivered.

**Reviewer 12-09 (Rating: 5)**

In all, I believe that this is a very high value proposal, and precisely the sort of work the NDIC/LRC should look at funding. Funding is requested at an appropriate level to achieve the stated objectives. The scope of work will address key questions concerning the feasibility of using UCG in North Dakota, and the 50/50 matching funds from their industrial partner (GNP) make this a good value proposition.

**OVERALL COMMENTS AND RECOMMENDATION:**

Please comment in a general way about the merits and flaws of the proposed project and make a recommendation whether or not to fund.



[2] "Value" – The value of the projected work and technical outcome for the budgeted amount of the project, based on your estimate of what the work might cost in research settings with which you are familiar.

[3] Financial commitment from other sources – A minimum of 50% of the total project must come from other than Industrial Commission sources to meet the program guidelines. Support greater than 50% from Industrial Commission sources should be evaluated as favorable to the application.

**Reviewer 12-07 (Rating: FUNDING MAY BE CONSIDERED)**

I recommend that funding may be considered if certain changes specified in this evaluation are made.

- One of the project goals "to develop a procedure to characterize the potential UCG sites" has been described numerous times before – starting around 1975. This procedure does not vary by state or country. If new software to interpret site data is available, that would be useful to know.
- The project, as written, would have low commercial impact but could be changed fairly easily to make it much more commercially oriented (see comments above and below).
- The "potential model site" should be expanded to a "potential model resource" – at least large enough to support a small commercial process, A minimum would be 1 square mile.
- The literature background search should include searching for the results of previous seismic surveys, some of which can be purchased
- The well program must be expanded to include well logging and hydrogeologic data acquisition (drill stem testing etc. This will add cost, some of which can be taken from the activities to develop a characterization plan. Steve Korom should be of great value in designing a good well testing procedure. If more money is needed, it might be taken from the thermal core testing studies.
- Better definition of the project tasks is needed, for example, well disposition after the cores are taken.
- A very short review of the permitting situation in North Dakota is in order –I understand there is no UCG permitting procedure in North Dakota but I assume it could adopt the Wyoming procedure??
- A short review of the groundwater usage situation on the resources in consideration is also in order. This review will not take much time given the state databases which are available.
- The proposal does not seem to be very well thought through, for example; the well drilling/testing/disposition aspects and the lack of critical path analysis.
- Note that a 'model' ucg site won't help much if it does not have commercialization potential i.e. resource, surface restrictions, groundwater usage etc.
- The drilling costs seem to be based on VERY optimistic estimates. My drilling costs in Wyoming are much greater. I assume the drilling rate of penetration is based on experience and is realistic.

I realize that the results of this study might not favor UCG development but, if this study at least touches on the most crucial commercial aspects of UCG in its resource evaluation, it will be a valuable study.

**Reviewer 12-08 (Rating: FUNDING MAY BE CONSIDERED)**

UCG could have a significant impact on utilizing the deeper lignite coal in North Dakota (the project proponent states that only 2% is surface mineable). Furthermore, combined with an adequate $CO_2$ management strategy, UCG could be a low carbon energy source from lignites. North Dakota could also have a unique advantage for $CO_2$ use for enhanced oil recovery, which could increase the revenue from a UCG project.

The project proponents have a good understanding of the overall requirements for evaluating the UCG technology and the adequacy of a specific UCG site. The proponents also appear to have the right set of technical backgrounds (geology, hydrogeology, petroleum engineering, computer modeling) to evaluate UCG technology. In addition, there appears to be significant physical analytical equipment and resources already in place to support the project. The industry partner (and co-funder) also would have a strong, aligned interest in thoroughly evaluating the UCG technology objectively from an ultimate commercialization viewpoint.

The proposed work scope (Tasks 1 – 5) appear somewhat ambitions given the budget and timeline. The tasks, decision points and timelines are however not adequately detailed.

It is recommended that funding be allocated to the project subject to the following items being updated:

- The proponents need to develop the next level of task break down to support the application.
- The computer modeling/simulation initiative could be a key quantitative tool to provide an initial evaluation of UCG sites in North Dakota lignites (Task # 4, Table 2, Page 24). It is recommended that this task be started at the project kick off, even with "estimated" physical property data for the target lignite seams. This will provide adequate time to develop/test the model before actual data is obtained from the drilling program. The actual test site data could then be used to update the computer models.
- The cost estimates for drilling/coring three wells at the selected site needs to be confirmed.
- The cost estimate and justification for additional equipment (high temperature loading cell) needs to be updated.

**Reviewer 12-09 (Rating: FUND)**

Primary Recommendation:

Based on my previous comments, I strongly recommend funding this proposal.

This proposal has a well-defined scope, a good execution plan, and the opportunity to have a significant impact on North Dakota's lignite resources. I do not perceive any major flaws in the proposal, and I am confident the team is well equipped to avoid significant delays in execution.

Secondary Comments:

1. This proposal actually contains two budgets, one at $486k (the primary budget) and one at $665k (an additional budget). The difference between the two is that, in the first, the team only proposes to drill a single core-recovery well, while in the larger budget they would drill three wells. From a technical point of view, more data is always better, but the question of whether to fund at a higher level will depend both on the NDIC/LRC's budget and on what additional value the team believes can be added by drilling two additional wells. If the larger budget is being considered, I might ask the team to submit additional justification on the added value they see for the additional wells. If they have existing characterization data suggesting strong horizontal heterogeneity, then the additional wells may be crucial. If the proposed site has a uniform, ``layer-cake" geometry, then the additional core and log profiles would have less value.

2. From the drilling quote, it appears the team intends to recover several hundred feet of core. No mention is made of exactly how this core will be handled, but some provision should be made to keep the core as close as possible to in situ conditions before testing---by bagging the core to prevent drying, etc.

3. Also, it should be kept in mind that the response of the underburden, *below* the target coal seam, can have a significant impact on the geomechanical response. Hopefully the recovered core section will extend into this underburden.

4. It is briefly mentioned that the team will use recovered core to due fracture characterization at the site. We wish to emphasize that this is an important effort, and extremely useful in scaling up mechanical properties measured at core-scale to field conditions. Also, it appears the team will use an acoustic emission technique to estimate in situ stresses. Hopefully they will attempt to correlate these stress estimates with independent ones from log data, leak-off tests at nearby wells, etc.

5. In the numerical modeling work, the particular UCG configurations that will be explored have not been mentioned. A variety of configurations can be employed depending on the well layout and linking technology. It would be interesting if the team can explore several of these multi-module configurations and make recommendations on the most appropriate scheme given the in-situ conditions.