1. OBJECTIVES

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

Reviewer 15-01 (Rating: 4)
The objectives of the proposed work is consistent with the North Dakota Industrial Commission/Lignite Research Council goals as the successful completion of the proposed project will lead to very useful data and tools for improving the performance of lignite-fired utilities.

The stated goal of the proposal is to use CFD modeling to develop relationships for designers and operators of high temperature slagging combustion (cyclone) and gasification systems that can be used on a daily basis to predict slag behavior as a function of fuel properties, system design and operating conditions to manage slag flow behavior.

Specific objectives mentioned address only a part of the program goals, which target the following: 1) study 3 cases, all related to cyclone gasifiers; 2) collect samples at 3 locations; 3) characterize slags, fuels, and entrained ash; 4) develop CFD models for the 3 cases; 5) conduct model testing and compare to operational experience; 6) based on models, develop useful relationships for daily plant use; and 7) manage and report results.

Reviewer 15-02 (Rating: 4)
The objective of this proposal is aimed at advancing methods to predict slag flow behavior in high-temperature slagging combustion and gasification systems; thereby, improving the performance of cyclone-fired combustion systems and high-temperature slagging gasifiers.

Reviewer 15-03 (Rating: 5)
Goals and objectives have been clearly stated in detail. They are consistent with furthering our industry and seeking ways and methods of improving existing operations.
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 15-01 (Rating: 3)**

Given the previous qualification and experience of the project team members and the proposed budget and timetable, the objectives outlined in the proposal should be likely achievable. The goals are to model both cyclone combustion and gasification, with heavy hints of fuel flexibility and widespread applications. Only one type of gasifier is modeled, with only three runs being characterized. No mention is made concerning gasification system studies, which use refractory liner materials. Gasification operates under reducing conditions, vs the oxidizing conditions in cyclone combustion – which the authors have not addressed, and which will produce different slag properties. Slagging gasification systems operate under pressure, which alone will not allow sampling and freezing of the high temperature phases existing. If mixed feedstock is used that involves petcoke, which the authors have discussed in their examples, petcoke has vanadium, which has very different properties in oxidizing vs reducing conditions. The types of carbon feedstock appear to target only lignite types of coals, but coals have a variety of different impurities which cause widely different slag chemistries. Gasification is a non-equilibrium condition, while cyclone combustion tends to be closer to equilibrium. The velocities of particles are also different in the two systems.

Besides not addressing the large differences in ash chemistry, the authors have not discussed the potentially large impact of char differences in the two systems, nor have they addressed any of the slag behavior differences in different areas of combustion vs the gasification chamber – they only discuss cyclone combustion systems.

What evidence do the authors have that all slag viscosity can be predicted for the bulk system based on literature and use of the Kalmanovitch Urbain model? Actual slag viscosities should be measured to validate a Kalmanovitch Urbain model prediction, which does not predict viscosities for all chemistry systems. Also, it is important to note that at least one Thermodynamic database predicts slag viscosity and crystalline phases, but this database is known to have issues in accurately predicting viscosity, and introduces many phases that do not occur. Also, the database has incomplete areas, such as with vanadium. Only information applicable to cyclone combustion is expected in this study, and it is questioned how widespread of an impact it will have. Without knowledge of the viscosity and phase behavior for a number of systems, it is questioned that the authors can accurately predict viscosity values needed for slag thickness calculations. Viscosity measurements are viewed as a critical property to measure.

Note in the proposal, lab data will not include viscosity curves as no equipment to do the measurement s is listed, and ash fusion data only gives some information related to viscosity behavior. Also, it is not indicated if the author’s ash fusion equipment measure in the reducing environment of gasification?

**Reviewer 15-02 (Rating: 4)**

Given the project’s approach, timeframe and budget, the objectives of the proposal are most likely achievable. However, the Standards of Success set for the project don’t include specific quantifiable goals. How much improvement can be obtained in terms of power plant operation?

**Reviewer 15-03 (Rating: 5)**

Methods and details are explained very well. Timetables and tasks are listed and all appear to be achievable.
3. **METHODOLOGY**

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 15-01 (Rating: 3)**

Modeling of slag flow in combustion and gasification systems is very difficult due to the complex physical and chemical transformations taking place inside the system, which effect the formation and properties of the slag flow. The proposed approach largely utilizes the sampling and analysis from different fuels, system designs, and operating conditions to develop models feeding into the CFD slag model. As far as the reviewer is concerned, this is an appropriate way to develop a new model for this complex process.

The author’s approach is not extensive enough for what they intend to do – indicating that only one or two specific company problems will be studied – not solving the widespread coal feedstock materials, and only solving one type of combustion system, which is cyclone combustion. It is questioned how gasification slags can be gathered that represent the slag phases at gasification conditions. It is also questioned how the small amount of slag data evaluated can become universally applicable to all cyclone gasifiers with all types of carbon feedstock or for all carbon feedstock processes.

**Reviewer 15-02 (Rating: 5)**

The methodology displayed in this proposal is well above average. The proposal reflects the attention to detail exhibited in work by the PI, Steven A. Benson, PhD.

**Reviewer 15-03 (Rating: 4)**

The methodology seems solid as well. Mr. Benson has done much work and many projects that lead up to this project, which is a furthering of this work. The work has been solid and relevant to the industry, and the methodology would be an extension of those proven in the past.

4. **CONTRIBUTION**

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

**Reviewer 15-01 (Rating: 3)**

The outcome of the proposed work will be helpful for the designer and operators to manager the slag flow behavior in a particular combustion and gasification systems to achieve the improved performance. Hence, it helps promote economic, efficient, and clean uses of lignite which is one major goal of the North Dakota Industrial Commission/Lignite Research Council. However, it will only solve, at best, a small part of the problem. The work targets specific company issues, but will not solve the industry-wide issues.

**Reviewer 15-02 (Rating: 4)**

The scientific and technical contribution of the proposed work could be very significant in addressing the goals of the LRC/NDIC. However, the potential contribution is not defined in quantifiable terms.
Reviewer 15-03 (Rating: 4)
I believe it could be very significant. The work has the potential to be even more impactful depending on the findings and how applicable/economical they can be in large scale, mine mouth operations.

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.

Reviewer 15-01 (Rating: 4)
The PI is very active and knowledgeable in the related fields. The reviewer believes the PI is aware of the current research activity and published literature; however, the proposal does not have many references to the others' work. In addition, there exists plenty of information on the slag properties in the literature which should be beneficial to the proposed model development.

The main author, Dr. Benson, has a good understanding of ash behavior; however, his application of it in sampling, property measurement, and how to use that information was not presented well. Examples are in the discussion of the importance of viscosity, but no recognition was given in the paper that combustion systems are oxidizing and gasification is reducing. This will impact phases such as vanadium or iron, which have multiple valences. It is also not clear how high temperature phases that exist at elevated temperatures will be accurately measured if the necessary rapid cooling is not practiced. Also, how will samples be taken from the modern high temperature, high pressure slagging gasifiers used in industry that represent what exists at the elevated temperatures?

Reviewer 15-02 (Rating: 5)
Dr. Benson is an internationally recognized authority in the area of the proposed work. The proposal has discussed current research, cited published literature, and thoroughly demonstrated exceptional awareness in the area of the proposed work.

Reviewer 15-03 (Rating: 5)
All investigators appear to be very aware of all related research activities and previous work.

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 15-01 (Rating: 4)
Most members of the research team have abundant experience and knowledge related to the proposed work and their background is above average; therefore, they should be able to support their assigned tasks. All have worked in their field for long periods of time.

Reviewer 15-02 (Rating: 5)
Exceptional – see previous answer.

Reviewer 15-03 (Rating: 5)
Exceptional background experience with all investigators.
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 15-01 (Rating: 3)**

The project management plan, proposed schedule, and financial plan are reasonable. According to Section 11, the project manager will be responsible for the coordination of efforts associated with testing and the development of models; however, no detailed plan for communication among different parties is provided in the proposal.

The overall plan seems good, but it is not clear why large sums of money are targeted to fuel “analysis and core” ($125,000) and not more to ash/slag characterization ($59,420), which seems to be critical to understanding what occurs with the carbon feedstock. It is not clear why only ash fusion is being done on the bulk slag.

**Reviewer 15-02 (Rating: 4)**

The project management plan identified in the proposal is very good. Proposed work involving several entities and activities requires additional detail not included within the page limit criteria set for the proposal.

**Reviewer 15-03 (Rating: 3)**

Good plan overall. I did not see much information in the way of communications with industry or investors (NDIC).

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 15-01 (Rating: 5)**

No equipment was noted as being purchased.

**Reviewer 15-02 (Rating: 5)**

No comment.

**Reviewer 15-03 (Rating: 5)**

Not aware of equipment that will be purchased.
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 15-01 (Rating: 4)**

The facilities and equipment available at MTI should be sufficient for conducting the measurement and analysis outlined in the proposal. MTI has a well-established record of conducting analysis of fuel and fuel-ash related material. In addition, some field tests will be conducted by Barr Engineering Co.

The authors have adequate equipment to evaluate the samples, but it is not clear why tests like viscosity are not being measured, nor why thermodynamic studies or mass balances are being conducted to determine what is happening to all carbon feedstock components.

**Reviewer 15-02 (Rating: 4)**

The facilities at MTI, UND and Barr are notably good for the proposed work.

**Reviewer 15-03 (Rating: 5)**

The tools and facilities that are available to this team are excellent.

10. **BUDGET**

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

**Reviewer 15-01 (Rating: 4)**

The budget is very reasonable, but appears to place too much emphasis on initial sample characterization versus characterization of slag viscosity behavior.

**Reviewer 15-02 (Rating: 4)**

The budget value of the proposal relative to the outlined work and financial commitments could be of high value contingent to the $240,000 cash commitment of project sponsor to be identified.

**Reviewer 15-03 (Rating: 3)**

This is a fairly expensive project, and therefore I am a bit critical on the value. The project has potential to produce very good technical data, but I also am concerned of the real life applicability of that data.

---

¹ “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.

² 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.
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.

Reviewer 15-01 (Rating: FUNDING MAY BE CONSIDERED)
The proposed project is aimed at improving the performance of cyclone-fired combustion systems and high-temperature slagging gasifiers by developing an effective tool to predict the slag flow behavior. The tool will be based on the three-dimensional CFD framework by integrating the chemical and physical process involved in slag formation. Extensive sampling and analysis of fuels, slags and ash under different system designs, and operating conditions are proposed to facilitate the slag model development and testing. The tool developed through this project might be limited to the fuels, system design, and operating conditions tested during the development. Hence, its applicability to other systems and operating conditions needs further verification. However, the same methodology and procedure could be applicable to a different system if it is demonstrated successful in this project. Overall, the reviewer would recommend considering funding this project.

Reviewer 15-02 (Rating: FUND)
The proposal contains key weaknesses:

- The matching cash contribution of $240,000 has not been identified,
- The Standards of Success are the development of a CFD approach and database which is not quantified in terms of power/gasification plant operation or efficiency, and
- This proposal lacks plant operation goals that can be measured.

This proposal contains key strengths:

- This project could improve lignite fired cyclone boiler performance,
- This project could improve performance of lignite fired advanced combustion and gasification systems, and
- The PI and project team are exceptionally qualified and have a successful record in the proposed area of work.

Subject to the commitment of matching cash contributions, this project merits funding.

Reviewer 15-03 (Rating: FUND)
The industry has benefited greatly from research that has led up to this point. I do believe that there could be more benefit to gain to take this research to the next level. My only concern would be to make sure that the research and deeper understanding leads to controllable or manageable variables. The amount of control of variables can be somewhat limited with mine mouth operations in North Dakota. This is referenced under “Objectives”, bullet 5 in the proposal.

I do recommend funding. The deeper understanding of the slagging characteristics should result in a benefit to the industry, especially as the industry is pushed toward more and more compliance projects that generally hinder the performance of our units as related to the slagging characteristics of lignite fuel.