TECHNICAL REVIEWERS' COMMENTS

LRC-LXXX-A: "Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks"

Submitted by: University of North Dakota Institute for Energy Studies
Principal Investigator: Dr. Steve Benson
Project Duration: 18 months
Request for: $94,000; Total Project Costs: $936,847

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 17-01 (Rating: 4)
The project goals of characterization and determining the forms and abundance of REE and the optimum concentration and separating methods, as well as developing technology in separating the fine particles is well aligned with the IC/LRC goals of maintaining and enhancing development of ND lignite and its products, preserving and creating jobs, environmentally sound processes, and additional value add potential.

Reviewer 17-02 (Rating: 4)
The objective is to determine the technical and economic feasibility of concentrating rare earth element (REEs) from the reject streams of a North Dakota lignite drying process. The objective is consistent with NDIC LRC statutory by demonstrating new marketable byproducts from lignite operations.

Reviewer 17-03 (Rating: 4)
The proposed project to determine the technical and economic feasibility of concentrating rare earth elements (REEs) from reject streams of ND lignite drying process aligns very clearly with the Statutory Goals and Purposes of the LRC. Phase 1 work, consisting of "sampling and characterization of coal and coal by-products, REE concentrations methods, identification and testing, evaluation of technical and economic feasibility of concentration methods, and design of separation technology", has the potential to ensure economic stability, growth, and opportunity in the lignite industry. The extraction and concentration of REE from lignite will promote economic, efficient, and clean uses of lignite and products derived from lignite.

The achievement of Phase I, which will develop a high performance, economically viable, and environmentally benign technology to recover REEs from ND lignite-related feedstocks, will help preserve existing jobs and production, and create economic growth potential in coal-producing counties. Potential revenues from developing technology to concentrate REE from coal feed stocks would be able to offset the additional costs plants will see under the Clean Power Plan rule.

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 17-01 (Rating: 4)
The 18 month timeframe seems achievable. If an areas timeframe could be challenged it seems as if it would be in Task 3 - the technical and economic feasibility study portion of the project.

Reviewer 17-02 (Rating: 4)
Given the approach, time and budget the objective is most likely achievable. A question may exist on the market value of the 2% concentrated product.

Reviewer 17-03 (Rating:4)
The project team has developed a very thorough and well thought out approach to identifying and concentrating REEs from coal feedstocks. However, there are substantial challenges to concentrating REEs from coal related feedstocks which typically have far lower concentrations than other REE containing ores. The detailed timetable and schedule laid out in the proposal indicates a very high level of understanding of the time and resources necessary to achieve the desired outcomes.

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 17-01 (Rating: 4)
The methodology in the proposal seems to be based largely on tried and true processes for the characterization and form determination. The separation of the fine particles seems to be in more of the development phase and is looking for the best methodology and processes for separating them, hence the methodology is tracking accordingly.

Reviewer 17-02 (Rating: 5)
Proposal prepared by Dr. Benson are exceptional. The technical and scientific methodology and organizational approach are well above average.

Reviewer 17-03 (Rating: 4)
As stated in the proposal and referenced therein, past work has identified the presence of trace elements including REEs within ND lignite coals and associated roof and floor materials. Additionally, the applicants have previously identified a more highly concentrated feedstock in that of the reject stream from the DryFinning™ process at GRE's Coal Creek Station. This more highly concentrated feedstock has the best potential to reach the required concentration of 2% by weight.

The project will utilize conventional processing beneficiation techniques but will be applied in a unique way to this feedstock. These processing techniques have not previously been used to concentrate REE bearing minerals, which are finer in size. However, this methodology has been proven to work on large scale operations.

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 17-01 (Rating: 4)
The contribution of determining the actual concentrations of REE in the field stock, waste streams, et al. coupled with developing the ability to separate from the fine particles is directly aligned with many of the IC/LRC goals and has the potential of brining a value added project to the ND lignite industry in an environmentally benign manner.

Reviewer 17-02 (Rating: 4)
The contribution of the proposed work may only be limited by the REE composition of the 2% product.

Reviewer 17-03 (Rating: 4)
The development of an economically feasible and environmentally benign method to extract REEs from ND's Lignite feedstocks will not only meet the goals of The North Dakota Industrial Commission but those of the Department of Energy. The potential for saleable by-products from the existing coal feedstock will contribute to preserving jobs and production and provide economic growth potential in coal-producing counties. The investigators reference the challenges facing end-users of REEs as China currently produces 90% of the global supply. If this research can develop a local feedstock of REEs, it would be a positive for the local economy while securing REEs for use throughout our national economy.

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 17-01 (Rating:4)
The principal investigator is an excepted expert in the field via past publications, experience, and previous projects. His awareness of current research, reference to referenced literature, and involvement with current projects is very good.

Reviewer 17-02 (Rating: 4)
The PI's awareness is evidenced in the referenced literature. Some additional REE market data would be helpful.

Reviewer 17-03 (Rating:5)
The proposal references many previous works that have been published identifying the potential of coal and specifically North Dakota Lignite as a feedstock for REEs. The proposal states that the fine particle separation testing may be accomplished by a novel particle separation technology currently being developed by UND and Envergex LLC as part of a DOE Phase I SBIR/STRR project. This illustrates the investigator's awareness of current research activity.

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 17-01 (Rating:5)
The background of the investigator is exceptional in this field, as well as, his association with the lignite industry in general and the research and development related to the development of efficient and clean energy production systems has been prominent.

Reviewer 17-02 (Rating: 4)
The teaming of the various organizations and individuals provides a well above average background for the proposed work.

Reviewer 17-03 (Rating:5)
The investigators background is very thorough as shown in the proposal. Dr. Steve Benson, Dr. Michael Mann, and Dr. Palo have decades of research experience and are well renowned in their respective fields. The research team has substantial knowledge and experience developing and testing new technologies for North Dakota's lignite industry.

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 17-01 (Rating:3)
The project management plan includes a well-defined milestone chart as well as a detailed schedule and description of each of the subtasks. The plan does address meetings with the investigators and subcontractors as well as the partners and gives additional avenues for inputs and detailed reports. The financial budget seems to be outlined well with cost allocations which seem reasonable. There are not any areas that seem to be readily missing nor exceptionally outlined, hence the plan seems adequate.

Reviewer 17-02 (Rating: 5)
The PI presents organization chart and milestone charts that are exceptionally good.

Reviewer 17-03 (Rating:4)
The detailed proposal illustrating the timeline, milestones and communication plan gives me great confidence that milestones will be met as required to deliver the results in a accordance with their plan. The team has a long history of leading and collaborating on large research projects involving large interdisciplinary and multi-organizational research projects such as this one.

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 17-01 (Rating:5)

Reviewer 17-02 (Rating: 5)

Reviewer 17-03 (Rating:5)
As the proposal states UND's Material Characterization Laboratory has an extensive suite of state-of-the-art analytical equipment. UND has many other resources such as fully equipped laboratories, wet chemistry laboratories, and mechanical and electrical fabrication shops. Barr Engineering also maintains licenses to software and modeling capabilities, which will be used in a supplemental role for this project. The required expertise and equipment needed to complete Phase 1 of this project is in place.

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 17-01 (Rating: 5)
The facilities and equipment available for the proposed research are exceptionally good. The lab and facilities are very well known, well published, and illustrated to have the latest equipment and software needed to perform these types of studies.

Reviewer 17-02 (Rating: 5)
The facilities available through the various participants are exceptionally good.

Reviewer 17-03 (Rating: 5)
UND and its partnering research firms such as Barr Engineering have been leaders in the development of new technologies currently in use or in consideration by the North Dakota Lignite Industry and related energy industries.

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 17-01 (Rating:5)
The proposed budget relative to the outlined work seems to be in line with what I would expect based on areas I am familiar with. Likewise, the financial commitment from other sources makes up a large portion of this project. The ask is very much within reason for the scope of this project.

Reviewer 17-02 (Rating: 5)
The proposal request is for ~10% of the total project cost from NDIC LRC. This proposal is of very high value.

Reviewer 17-03 (Rating:5)
The NDIC Commission threshold of 50% is being met as stated in the proposal with North American Coal and Great River Energy each contributing $47,000. The NDIC is then being asked for the remaining $94,000 dollars to bring the total funding to the 20% cost share required by the Department of Energy. With the total cost of Phase I of $871,847, the requested amount of $94,000 represents a very high value to the NDIC.

[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 17-01 (Rating: FUND)
The overall project goal is to develop a high performance, economically viable, and environmentally benign technology to recover rare earth elements from ND lignite coal, associated sediments, and lignite drying system reject streams. With the initial levels of REEs approaching 3000 parts per million, the dry fining process appears to concentrate the REEs to a level significantly higher than previously examined feedstocks giving it a significant potential to explore. With the proposed combination of the tried and true characterization and separation techniques coupled with new development technology for the fine particle separation (UND/Envergex) the proposal seems sound.

The project seems to fit under 43-03-02-02 (Eligible and ineligible projects) as it is looking at developing a market for other byproducts derived from lignite. Likewise, the funding of the project is currently well funded and well below the 50% of total cost, and in all actuality funded soundly by other avenues. The application format and requirements under chapter 43-03-04 were followed well and no categories were found to be missing.

With the funding levels being well under the 50% match guidelines there seems to be considerable upsides to moving forward with the study including:

• Significant growth potential if technology and concentrate is proven at a ND and global level.
• Added incentive in the adoption of dryfining technology and thus add further incentives by the cleaned coal from the concentrating process will be recycled back to the plants boiler, decreasing waste, which could add value to the coal.
• Potential of heavy elements will report to the concentrate there is also a potential for selective removal of toxic metals from the waste material if deemed a valuable and saleable byproduct.
• Goals of maintaining and enhancing development of ND lignite and its products, preserving and creating jobs, and reducing the environmental impacts.

The downfalls at this funding level are minimal compared to the upsides this could bring. With that being said

Downfalls:
• Concentrating REE in coal related feedstocks is a challenge and many of the concentrating/extraction techniques proposed are well known and used extensively at large scales, but the methods have not been used to concentrate REE bearing minerals that are associated with minerals in finer size fractions.
• The value of the 2% REE concentrate will be difficult to determine as the cost of the downstream extraction/separation process to get the pure REE elements and will be set by market or negotiation with the downstream separation plan; hence would it be economical?
• The roof, floor, and parting ppm levels are relevantly low compared to the waste stream from dryfining hence the benefits of this research would likely require dryfining to achieve them.
Based on the scope, funding level, expertise, and potential benefits of this project I would recommend funding this proposal.

Reviewer 17-02 (Rating: FUND)
This proposal is well written, the work is well documented and the participants are exceptional. This is an interesting area of investigation for NDL. The weakness in the proposal is a lack of detail on the $value of REE and REE concentrates. Some indication of costs would be helpful in balancing why and how much effort should be spent in this area.

Reviewer 17-03 (Rating: FUND)
The North Dakota Lignite Industry is facing ever more stringent rules including the Environmental Protection Agency's recently finalized Clean Power Plan; therefor the industry is faced with ever increasing costs of compliance. Ultimately, operators are looking to further develop beneficial uses of the resource to remain competitive.

The proposal identifies the most likely feedstock that will provide the highest probability of meeting the 2% concentration requirement of the DOE as the reject fines from the DryFinningTM process. However, the project team will determine the abundance and form of REEs in multiple locations throughout GRE's generating process. These results should help other plants test and identify the potential to extract and concentrate REEs from coal sources at their sites.

The potential to develop an additional revenue stream from extracting and concentrating rare earth elements from previously identified feedstocks meets many of the Lignite Research Council Goals. Development of this technology at the GRE station has great potential to provide additional markets for North Dakota lignite byproducts. The additional revenue streams would likely create new jobs, preserve existing jobs, and ensure the economic stability, growth, and opportunity of the lignite industry.

Therefore, I recommend that the NDIC fund Phase I of the this project to develop a high performance, economically viable, and environmentally benign technology to concentrate rare earth elements from North Dakota lignite for the proposed cost share of $94,000