TECHNICAL REVIEWERS' COMMENTS

LRC-LXXX-B: "Managing Aerosol Emissions from CO2 Capture Systems"
Submitted by: Energy & Environmental Research Center (EERC)
Principal Investigators: Bruce C. Folkedahl and John P. Kay
Project Duration: 10 months
Request for: $300,000; Total Project Costs: $600,000

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 17-04 (Rating: 4)
The CO2 reductions in the Clean Power Plan pose a significant threat to the State's lignite industry. Currently, amine processes are the best way to capture CO2 and aerosols can significantly affect the performance and cost of this technology. Better understanding of lignite-generated aerosols will help maximize the potentials of amine based capture systems, thereby helping protect the lignite industry.

Reviewer 17-05 (Rating: 5)
The objectives are easily identified in bulleted format and align well with the stated goals in this reviewer's opinion.

Reviewer 17-06 (Rating: 4)
Page 4 of the project proposal is quite clear; "specific" objectives are also identified as well as potential new ones predicted.

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 17-04 (Rating: 4)
The proposal's approach, timetable, and budget all seem to be aligned, making the objectives highly likely to be achievable.

Reviewer 17-05 (Rating: 5)
The application focuses on the scope of work associated with a $600,000 effort over 10 months. Should an additional $300,000 be secured through the U.S. DOE, the scope and schedule will be amended to support pilot testing of possible solutions.

Reviewer 17-06 (Rating: 3)
This 1st Phase, the identification phase, seems to follow known and proven techniques/methodologies. Experienced team and 10 month schedule to measure, model, and report seems adequate.

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 17-04 (Rating: 4)
The approach and methodologies described in the proposal are very logical and well thought out. The equipment and techniques to be used are well-accepted practices.

Reviewer 17-05 (Rating: 4)
The methodology is clear and makes good sense.

Reviewer 17-06 (Rating: 3)
Overall methodology sounds like a good approach however, would have a liked a bit more clarity on the test protocol and details/projected output from the various techniques.

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 17-04 (Rating: 4)
If the Federal government is requiring CO2 capture at electrical generating plants, the understanding of processes that will impede or increase the costs of capture are critical to understand. The generation of aerosols in lignite-fired units has the potential to decrease performance and increase costs, if the aerosols are not understood and dealt with. As such, this research is direct on point with the NDIC's goals of protecting the State's lignite industry.

Reviewer 17-05 (Rating: 4)
As highlighted in the proposal, the post combustion capture process using amines is the most mature technology for controlling CO2 emissions. Management of amine based degradation and loss is important in the application of this technology.

Reviewer 17-06 (Rating: 4)
The management of aerosol's from carbon capture remains an open issue as witnessed at site's where significant prototype testing is being accomplished. Therefore, identifying the mitigation methods and defining strategies is imperative going forward.

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 17-04 (Rating: 5)
The PI's and the staff's qualifications and grasp of the research appears to be very good and may be as complete as anyone in the world.

Reviewer 17-05 (Rating: 5)
The principal investigator is clearly knowledgeable in this area.

Reviewer 17-06 (Rating: 4)
Dr. Folkedahl and Mr. Kay are indeed recognized as experts in the emission capture and measurement techniques needed to accomplish this 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 17-04 (Rating: 5)
The resumes of the PI and his staff indicate they have board and detailed experience covering all aspects of the proposal's tasks.

Reviewer 17-05 (Rating: 5)
The principal investigator has invaluable experience in this industry.

Reviewer 17-06 (Rating: 4)
The work at the EERC on various emissions capture and measurement schemes is well known and respected.

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 17-04 (Rating: 3)
The management plan, schedule, and financial plan detailed in the proposal are adequate and should meet the needs for a successful project completion.

Reviewer 17-05 (Rating: 4)
The plan is clear consisting of measuring aerosols, modeling possible causes and solutions, followed by proposing solutions to be pilot tested in a future phase of work. Communication with a steering team of industry participants is a great approach.

Reviewer 17-06 (Rating: 3)
Rather over-simplified chart included which could be expanded to include the overall test plan. Budget looked reasonable. Monthly calls and quarterly reports should be sufficient to keep team members up-to-date.

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 17-04 (Rating: 5)
The proposal does not plan to purchase any equipment

Reviewer 17-05 (Rating: 5)
This reviewer understands that no equipment will be purchased with funds used for the proposed work.

Reviewer 17-06 (Rating: 5)
Supplies are budgeted but not defined as equipment as such therefore, unclear as to whether or not any will be purchased but believe "none" as the proposal is currently written. Maybe EERC can clarify?!

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 17-04 (Rating: 5)
The equipment and facilities at EERC, identified in the proposal, are excellent and well suited to meet the research needs.

Reviewer 17-05 (Rating: 5)
The EERC and UND bring abundant resources to make this effort a success with guidance from industry sponsors.
Reviewer 17-06 (Rating: 3)
Would like a bit more detail on "supplies".

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 17-04 (Rating: 4)
The cost of this proposed research could be a very good value for the State and the ND lignite industry. The commitment of Mitsubishi to sponsor the project is good; however, five more sponsors are needed, according to the budget. Hopefully, one or more of these sponsors will be ND utilities. Finally, approval and funding of this project should be held until they have commitments from sponsors for 50% matching funds. The project's work plans involve testing at ND plants that belong to project sponsors, without this ND utility sponsors, a number of the proposal's statements will be difficult to fulfill.

Reviewer 17-05 (Rating: 3)
The value seems at least average. The value greatly increases if an additional $300,000 is secured from the U.S. DOE expanding the scope of work. Thus far, only Mitsubishi Heavy Industries have committed to $50,000 of the $300,000 industry participation required. However, the request is contingent upon securing the remainder of the required $300,000.

Reviewer 17-06 (Rating: 4)
It has been noted that the aerosol issue remains unresolved and therefore, mitigation strategies will indeed need to be identified before mass carbon capture methods are implemented!

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[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.

<u>OVERALL COMMENTS AND RECOMMENDATION</u>:

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 17-04 (Rating: FUND)
Aerosols are currently causing major problems and costs at a demonstration facility using amine CO2 capture. The cost of this research versus to potential costs of not understanding the problems is very small, making this proposal a good value added project.

If the proposal is lacking in any technical items, it is in not mentioning the potential environmental harm that can occur if aerosols carry amine out into the area around the plant. This is not a pure technical issue or an economic consideration, but environmental impacts can be significant and their avoidance is very important to the lignite industry in North Dakota.

Reviewer 17-05 (Rating: FUND)
This reviewer recommends funding the proposed $300,000 grant contingent upon a total of $300,000 industry participation commitment of which only $50,000 had been secured as of the April 1st application deadline. This reviewer's only concern is if industry is considering applying post combustion CO2 capture technology using amines. If not, the support won't be available and the proposed work may be of little value. This technology is the most technically advanced CO2 emissions control, but has proven to not be economically feasible thus far.

A few suggestions from this reviewer:

- *Highlight the MHI commitment secured and work to secure further industry participation*
- *Quantify this problem of amine loss. Perhaps ppm loss experienced compared to ppm loss that's considered acceptable from an emissions permitting point of view. It would also be helpful to quantify the associated financial impact of the amine loss multiplying the loss over a time period by the cost to replace the amine.*
- *Elaborate on how the aerosols will be measured at undetermined sponsor site(s). Will there be probes placed into the flue gas streams collecting samples to be analyzed at different locations from boiler outlet throughout the air quality control systems and finally at the stack? Will there be testing at different electrical generation unit loads?*
- *What technologies are expected to mitigate the formation of aerosols or associated amine loss? Understanding what causes the aerosol formation from sample collection and modeling will help determine possible solutions. Are there any theoretical systems or changes known to try such as a wet electrostatic precipitator or perhaps changes in the combustion process to prevent forming the aerosols?*

Thank you for your work in this industry striving for continued use of coal in an economically responsible manner.

Reviewer 17-06 (Rating: FUND)
The proposal is a valid one, as earlier stated. It would be worthwhile to see a bit more detail on the schedule, test protocol, and budget breakdown. My recommendation is to FUND the project since the identification of remedial strategies is needed going forward with carbon capture. It is also believed that EERC can provide the added information and is quite capable of getting this project completed.

MANAGING AEROSOL EMISSIONS FROM CO_2 CAPTURE SYSTEMS

Authors' Responses to Reviewers' Comments

1. No response required.
2. No response required.
3. See response below related to test protocol.
4. No response required.
5. No response required.
6. No response required.
7. No response required.
8. See response below related to Supplies and Equipment.
9. See response below related to Supplies and Equipment.
10. Reviewer 17-04 is correct in the assessment that testing at power plants is critical to fulfilling project goals. It is anticipated that the EERC will perform aerosol sampling and analysis at plants based on project sponsorship.
11. Reviewer 17-04 has raised the issue of potential environmental impacts of amine solvent loss. The project team recognizes that this may be an issue if it is discovered that significant amine loss is occurring. However, until actual CO_2 capture systems are sampled and quantified measurements are performed, the environmental issue is an unknown. It is the intent of this project to perform the measurements required to produce the data that will enable amelioration efforts to be established if needed.

    Reviewer 17-05 has raised the question of utilities actually considering amine CO_2 capture systems for deployment which will drive interest in supporting this study. The EERC has already received commitment and support from Mitsubishi Hitachi (MH), which is a supplier of CO_2 capture systems technology, and interest from utilities and coal companies in North Daktoa and elsewhere. The EERC is working diligently to add other industry support. Additionally, the EERC has received verbal commitment from SaskPower to participate in investigation of emissions from CO_2 capture systems. SaskPower has a demonstration-scale amine CO_2 capture system in operation at its Boundry Dam Facilities near Estevan, Saskatchewan.

    The Reviewer also asked about potential amine loss and costs of that loss. From some modeling work performed at the EERC, it is estimated that the loss of amine may be in the range of 100s of gallons a day and, possibly, significantly higher. Using a rough cost of $1.00 a pound for the amine solution at 800 pounds an hour loss gives costs of approximately $2000 solvent loss of 200 gallons a day, assuming 10 pounds/gallon of solution gives a cost/day, or $60,000 a month.

    The Reviewer wanted more information on how the sampling for aerosols will be conducted. Sampling will not be conducted under varying loads. Samples will be taken at

different locations in the flue gas path, and these locations will be dependent on the types of particulate control devices installed at the plant where the sampling takes place. Two sampling methods will be used. One method will incorporate a Dekati 13-stage impactor.

From the Dekati Web site, "DLPI (Dekati® low-pressure impactor) is a cascade impactor to measure airborne particles in 13 size fractions between 30 nm and 10 µm. The impactor has a simple and robust structure, and it can be used in any application where particles <10 µm exist in the sample:

- Wide particle size range; 30 nm – 10 µm, 0 nm – 10 µm with filter stage.
- 12 particle-size fractions, 13 with filter stage
- 30-lpm sample flow rate
- Robust, stainless steel construction
- Can be heated up to 200°C
- Excellent calibration data

Typical applications for the DLPI impactor include air quality monitoring and emission measurements from stationary sources."

This methodology will acquire physical samples that can then be analyzed for chemistry and morphology using a scanning electron microscope. The second methodology will utilize a TSI scanning mobility particle sizer (SMPS). This technology is a dynamic sizing technique that will not collect samples but will give an accurate size distribution of particles in a gas stream:

- High-resolution data – up to 167 channels
- Broad size range – from 1 to 1000 nm
- Fast measurements – complete size distributions in 16 seconds
- Wide concentration range from 1 to 10^7 particles/cm^3
- Flexible setup options; choice of water or butanol condensation particle counter fluid; choice of traditional or nonradioactive neutralizer
- Computer automated flow control
- ISO 15900:2009 compliant particle-sizing method
- Easy to set up and operate (from TSI Web site)

Reviewer also expressed interest in what types of mitigation techniques may be used. While the purpose of this project is at least in part to aid in determining those solutions, the project team has postulated some potential amelioration technologies. Based on some recent work in Europe, it appears that part of the cause of the solvent loss may be due to the fine fraction of nanometer-sized particles that enter the CO_2 capture system providing condensation sites for amine solution. Therefore, techniques to lower the amount of aerosols or nanometer-size particles entering the capture system will decrease losses. Previous work at the EERC (Hurley and Katrinak, 1992) has shown that, for North Dakota lignites, the smallest fraction of particulate that is relevant to this study is primarily alkali, alkaline-earth elements, and sulfur species. Several studies have shown that the introduction of kaolinite clays can be effective in capturing these species, allowing for their removal from the gas stream by conventional particulate control methods (Gale and Wendt, 2003; Hurley and Kartrinak, 1992; Takuwa and Naruse, 2007). This may one approach to reduction of aerosol emissions.

Reviewer 17-06 asked about more information on the schedule, test protocol, and the budget. The schedule will be delineated in finer detail once all of project sponsors have been gathered, as they will have a significant role in shaping project direction. The test protocol will utilize the technologies described above which are standardized methodologies. Detailed test plans will be formulated once all project partners have been assembled and a plant site for sampling identified. Budget breakdown is as below, and a description of the difference between supplies and equipment is provided, as asked for in earlier questions:

- Sampling at field sites 45%
- Modeling and data analysis 30%
- Reporting 15%
- Management 10%

Supplies: Supplies include items and materials that are necessary for the research project and can be directly identified to the project. Supply and material estimates are based on prior experience with similar projects. Examples of supply items are chemicals, gases, glassware, nuts, bolts, piping, data storage, paper, memory, software, toner cartridges, maps, sample containers, minor equipment (value less than $5000), signage, safety items, subscriptions, books, and reference materials. General purpose office supplies (pencils, pens, paper clips, staples, Post-it notes, etc.) are included in the F&A cost.

Equipment All equipment must meet the basic criteria of having a cost of $5000 or greater, does not change materially with use (is not consumed in use and retains its original identity during the period of use), and has a useful life to the EERC > 1 year.

REFERENCES

Gale, T.K.; Wendt, J.O.L. Mechanisms and Models Describing Sodium and Lead Scavenging by a Kaolinite Aerosol at High Temperatures. *Aerosol Science and Technology* **2003**, *37* (11), 865–876.

Hurley, J.P.; Katrinak, K.A. *Determinations of Ash Formation and Deposition Mechanisms at Minnesota Power Clay Boswell Station*; Report for Minnesota Power and U.S. Department of Energy Cooperative Agreement No. DE-FC21-86MC106437; Energy & Environmental Research Center: Grand Forks, ND, July1992.

Takuwa, T.; Naruse, I. Mechanisms of Fine Particulates Formation with Alkali Metal Compounds during Coal Combustion, *Fuel* **2006** *85* (5–6), 671–678.