Minnkota Power COOPERATIVE
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February 3, 2022

Ms. Karlene Fine
Executive Director
ATTN: Lignite Research Development and Marketing Program
North Dakota Industrial Commission
State Capitol, 14th Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Subject: Minnkota Power Cooperative Proposal for Project Tundra "CREST Study"

Dear Ms. Fine:

Minnkota Power Cooperative is pleased to submit an original and one copy of the subject proposal in partnership with Fluor Corporation, the Energy & Environmental Research Center (EERC), Sargent & Lundy, Wanzek and others. In addition to the $100 application fee, you will find an application for your support of the research and development required to commercialize a transformational technology that will provide widespread benefits to the lignite industry. The Project Tundra team is committed and ready to complete the project as described in the proposal with the support of the Commission, which is imperative to the development of new technologies securing the continued use of lignite in North Dakota.

If you have any questions, please contact me by phone at (701) 794-7261 or by email at cbleth@minnkota.com.

Sincerely,

Craig J. Bleth

Craig J. Bleth
Minnkota Senior Manager of Power Production

Lignite Research, Development and Marketing Program

North Dakota Industrial Commission

Application

Project Title: Project Tundra "CREST" Study

Applicant: Minnkota Power Cooperative

Principal Investigator: Craig J. Bleth

Date of Application: February 3, 2022

Amount of Request: $5,415,000

Total Amount of Proposed Project: $10,830,000

Duration of Project: 10 months

Point of Contact (POC): Craig J. Bleth

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ABSTRACT

Objective: The project objective described in this application is to conduct the final body of study and engineering work needed to produce **c**onstruction-**r**eady **e**ngineering, **s**cheduling, and pricing **t**erms (CREST) for a commercial carbon capture system retrofitted to a power plant fueled by North Dakota lignite. The CREST work will include (a) steam turbine modeling for steam supply for carbon capture, (b) designing the systems, piping, and structures needed for steam integration, (c) engineering for the other impacts of an extraction steam supply strategy, (d) design integration of optimization opportunities that are aimed at reducing the projected cost of carbon capture, and (e) a more detailed emissions analysis, icing studies, and dispersion modeling. These are the elements that will support a possible start of construction for Project Tundra by the end of 2022 while informing other project developers of the impact of certain design decisions for their projects. The goal of Project Tundra is to demonstrate post combustion carbon capture (PCCC) and storage in North Dakota, preserving the use of lignite and the associated jobs, ensuring enough reliable and dispatchable power is on our grid, and moving North Dakota closer to its carbon neutral goal.

Expected Results: The project will result in data on real-world solutions to key issues encountered when deploying PCCC on facilities in North Dakota such as (1) PCCC design and construction methods for extreme cold climates, (2) the impacts of, and mitigations for, the ultra-fine particulate produced from combustion of North Dakota lignite, (3) final design of the optimization opportunities identified in prior engineering and study, and (4) the means and methods for extracting large volumes of steam from lignite-fired utility boilers. The data-driven solutions resulting from this project will thereby significantly reduce PCCC capital and operating costs while increasing net CO_2 captured. Prior studies have only estimated PCCC costs,

however, this project will provide the industry with a real-world price and set of terms for the lump-sum turn-key construction of Project Tundra, against which other PCCC developers will calibrate their project estimates. Large-scale PCCC places North Dakota in a leadership position on the development and deployment of technological solutions for carbon.

Duration: The project schedule is ten (10) months with an anticipated start date of March 1, 2022. The engineering and study work will take eight months and then an additional two months to complete the final report.

Total Project Cost: The proposed project budget is $10,830,000, with $4,915,000 anticipated in the form of cash from Minnkota, $5,415,000 from the North Dakota Industrial Commission (NDIC) and $500,000 from Fluor Enterprises.

Participants: The project lead is Minnkota Power Cooperative, and the project will be conducted in partnership with the NDIC through the Lignite Research Council and the Lignite Energy Council. Also participating will be the Energy & Environmental Research Center (EERC), Fluor Enterprises, Inc (Fluor); Sargent & Lundy (S&L); Wanzek; and others as needed and identified during the project. This team brings together a group of industry leaders with a track record of success in lignite, engineering, construction, and carbon capture technology. With the expertise and drive of the Project Tundra team, the outcome will be a commercial PCCC project ready for the start of construction by year end in North Dakota.

PROJECT SUMMARY

Energy leadership is deeply ingrained in North Dakota, as evidenced by the environmentally sound means used to produce our natural resources, like lignite, and the industry's constant innovation. Project Tundra (Figure 1) is the next step in continuing our industry leadership as the electric sector looks for ways to reduce carbon intensity.

Figure 1. Project Tundra

Policy leaders in North Dakota recognize both the challenge to the lignite industry with continued pressure to reduce carbon emissions and the enormous economic potential for our industry if there is access to affordable carbon dioxide storage in the state. North Dakota and other energy producing states are seeking to stay competitive by reducing the carbon intensity of products produced in their states. Project Tundra fits entirely within that vision for the future of North Dakota and will serve as a model for the next PCCC projects.

Project Tundra will demonstrate that coal-powered electric generation can produce low carbon energy while maintaining grid reliability. The Project Tundra team requests that the North Dakota Industrial Commission (NDIC) help fund a CREST (Construction Ready Engineering, Scheduling, and *pricing* Terms) scope of work that will be the final piece needed to implement PCCC on the 700-MW Milton R. Young Station (MRY).

The following specific objectives for the CREST study have been identified:

- Finalize the design for the capture facility using data-driven results.
- Evaluate and incorporate the PCCC cost optimization opportunities developed during the FEED. (Note: Final Report for the Tundra FEED is in progress and expected to be issued by the end of May, 2022)
- Create a design that takes a "station PCCC" approach rather than a "unit PCCC" approach, where multiple coal-fired boilers will supply steam and flue gas to one PCCC unit.
- Produce a final, firm lump-sum real-world price and execution schedule for the construction of Tundra to support tax equity financing and start of construction.

To accomplish the above objectives, the project has been structured into eight tasks: Task 1 – Project Management and Technology Transfer, Task 2 – Steam Extraction Studies and Steam System Design, Task 3 – Aerosol Measurement in Support of Dual Flue Gas Supply: Task 4 – Evaluation and Integration of PCCC Cost Reduction Opportunities, Task 5 – Multi-Unit Flue Gas Ductwork Transient Analysis and Protection System Design, Task 6 – Icing Study and Protection System Design, Task 7 – Evaluation of Operational Safety Using Gaseous Dispersion Modeling, and Task 8 – Construction Project Definition and Documentation.

Project deliverables will be a report that (a) details the results of the Tasks, (b) outlines the plans for addressing issues and incorporating solutions into final design, and (c) a template for the technical details needed for an EPC contract for turn-key construction of a PCCC with a firm price, schedule, and guarantees.

The CREST study work is anticipated to take a total of ten months, with eight months to complete Tasks 2-8, followed by two months to complete the final report. The expected start date is March 1, 2022 and the proposed budget is $10,830,000, with $4,915,000 anticipated in the form of cash from Minnkota, $5,415,000 from the North Dakota Industrial Commission (NDIC) and $500,000 in the form of cash from Fluor Enterprises, Inc.

PROJECT DESCRIPTION – PROJECT TUNDRA CREST STUDY

Objectives: The goal of this project is to complete the CREST study which will (1) help pave the way for financing and potential start of construction on Project Tundra by the end of 2022 and (2) establish a template for other PCCC projects in North Dakota. The CREST study will accomplish the next steps (identified in the Tundra FEED co-funded by NDIC) needed for a lump-sum EPC proposal with a firm fixed price and schedule. The overarching goal of Project Tundra is to implement CCUS as a means to preserve lignite-based energy production in North Dakota and begin to decarbonize North Dakota's energy industry while creating a low-carbon intensity firm electric resource for the grid.

Method: Eight tasks have been identified and described below that will make it possible to accomplish project objectives.

Special Note: Minnkota Power reserves the right to monitor and review the work and progress and make changes to the project team (in consultation with the Lignite Research Council [LRC]

and NDIC) as it deems necessary to ensure the timely and successful completion of the CREST project.

SCOPE OF WORK

Task 1 – Project Management and Technology Transfer

The planning and management of all project activities will be performed by Minnkota Power with support from EERC personnel over the duration of the project period of performance. This task includes coordination of project activities, providing direction to the project team, and providing updates and obtaining inputs to prioritize the project focus. Specific activities will include the preparation of quarterly progress reports according to NDIC requirements and the preparation of a comprehensive final report.

Technology transfer activities will include, at a minimum, the presentation of results through meetings and reports, and presentations at relevant technical conferences. Results of all tasks will be provided in project meetings and reports. All additional deliverables noted in the following tasks will be summarized in quarterly and final reports.

Task 2 – Steam Extraction Studies, Steam Supply to PCCC design, Impact of Steam Extraction on Existing Power Plant Facilities and Operations

The Front End Engineering Design (FEED) study performed by Fluor from April 2020 through December 2021 identified several potential project cost reduction opportunities. The most impactful opportunity is to change the PCCC steam supply from new natural gas boilers to steam extraction from the existing Unit 2 and Unit 1 lignite-fired generating units. The base case design of the Project Tundra PCCC was sized to process 100% of the flue gas from Unit 2 in addition to the flue gas from new natural gas fired boilers for a total design capacity of 12,978 short tons of

CO_2 per day. Elimination of the new natural gas boilers frees up flue gas processing capacity over and above the amount produced by Unit 2. MPC has therefore decided to utilize the current PCCC design capacity to also process a portion of the flue gas from Unit 1. This results in the processing of over 70% of the entire station's projected future flue gas, compared to the 58% contemplated in the FEED base case design with the gas boilers.

Preliminary evaluation of extraction steam capabilities indicated that Unit 2 steam extraction alone will not provide enough steam for the PCCC at full load under all operating conditions. However, it appears that sourcing extraction steam from both Unit 2 and Unit 1 will not only be able to provide for the steam demand of the PCCC, but with the added benefit of maintaining operational flexibility for the station. Elimination of the natural gas boilers has the additional benefits of (1) allowing the project to reduce the plot plan and realize significant capital cost savings, (2) avoiding the need for a new 25-mile natural gas pipeline which has significant cost savings, and (3) avoiding significant potential future price volatility of natural gas.

In this task, engineering and study work will (a) more fully determine the extraction steam capabilities from Unit 2 and Unit 1, (b) evaluate any structural or mechanical issues that must be addressed in extraction system design, (c) evaluate the dynamics of combining extraction steam from two units and the control and monitoring systems needed, (d) evaluate seasonal steam condensate return conditions and the impact on steam turbine condensers, and (e) identify operational impacts caused by extraction from two coal units that will need to be addressed in detailed design. The lessons learned from the work done in this task will be important guidance for anyone considering installing PCCC on lignite coal-fired stations in the state.

A. Siemens Unit 2 Steam Turbine Thermal Modeling and Evaluation of Modifications Required

Preliminary evaluation of the extraction steam capabilities for Unit 2 identified no fatal flaws. Further study is required, however, to first confirm preliminary results and then to develop design parameters that would allow safe and efficient steam extraction from the Siemens steam turbine generator (STG) associated with Unit 2. These evaluations are required to ensure that sufficient steam is available at the required temperature and pressure for use in the PCCC while also ensuring operational integrity of the Unit 2 Siemens STG. Specifically:

- Detailed thermal modeling at various operating loads and ambient temperatures to determine most favorable location in the STG piping for extraction of steam and the impact on Unit 2 operating conditions while supplying steam to the PCCC.
- Integration of extraction steam operating parameters into the PCCC process design.
- Evaluation of structural and mechanical design of the STG when extraction steam is delivered to the PCCC at various operating conditions and during upset conditions.
- Evaluation of existing STG control systems and instrumentation, then design of modifications and additions required for safe and efficient operation.
- Evaluation of STG piping and then design the steam extraction interface considering:
    - Thermal and mechanical stresses associated with startup, operation and shutdown
    - Response time requirements for a new extraction steam control valve to assure safety of operation and to assure sufficient steam is delivered to the PCCC under various STG and PCCC operating conditions.
- Design and integration of new control system interfaces and logic to accommodate the new extraction steam control valve and monitoring systems.

- Design of the STG steam piping interface, resulting in a single header containing the combined steam from Unit 2 and Unit 1 for delivery to the PCCC.
- Evaluate the impact of return condensate temperature on the feedwater heaters and extraction piping under various seasonal scenarios and identify design parameters – especially for extreme (hot-cold) weather operation.
- Evaluate existing condensate drain systems and design modifications to assure safe operation of the STG during start up, operation and shut down conditions in a cold climate.
- Provide cost and schedule estimate for the required STG, piping, control system, instrumentation and other equipment modifications and additions required to implement extraction steam from Unit 2.

B. General Electric Unit 1 Steam Turbine Thermal Modeling and Evaluation of Modifications Required

As noted above the extraction steam capacity on Unit 2 alone identified a potential shortfall in steam to process 12,978 short tons of CO_2 per day. Preliminary evaluation of the extraction steam capabilities of Unit 1 identified no fatal flaws, however, further study is required to (1) confirm preliminary results and (2) to develop design parameters that would allow safe and efficient use of extraction steam from the GE STG associated with Unit 1. These evaluation methodologies and deliverables are the same as those listed above for Task 2A, the Siemens STG.

C. Evaluation of Unit 2 and Unit 1 operational dispatch and environmental permit impacts resulting from the use of extraction steam for PCCC operation.

The implementation of steam extraction from Unit 2 and Unit 1 will have operational implications affecting the dispatch of the MRY facility and these impacts must be determined and quantified. It must also be verified that there are no material impacts on MRY's existing permits and operating authorization. The thermal modeling described in the STG evaluation tasks above, will provide the information needed to detail the performance impacts of extraction on the electric output and operating characteristics of MRY. In this task, the operational impacts will be documented (along with confirmation of no permit impacts) in order to provide a full understanding of the cost and the value of extraction steam.

D. PCCC design impacts and adjustments resulting from the use of extraction steam.

Beyond the direct thermodynamic impacts of using steam extraction as the steam supply for the PCCC, there are numerous physical implications to project design, including plot plan, emissions characteristics, electric system capacity and dispatch characteristics, reboiler sizing and design, condensate collection and return system, building heating and freeze protection, startup and shutdown protection system, etc. This task will document the implications of extraction steam for other PCCC systems.

Task 3 – Aerosol Measurement in Support of Dual Flue Gas Supply

The significant cost reduction opportunity of eliminating the natural gas boilers provides the PCCC with capacity to accept flue gas from the Unit 1 boiler. This creates a unique design that takes a "station PCCC" approach rather than a "unit PCCC" approach, where multiple coal-fired boilers will supply steam and flue gas to one PCCC unit. The objective of the aerosol

measurement study is to characterize flue gas from both Unit 1 and Unit 2 under a wide range of coal quality and operating conditions, and utilize that information to inform the design of the particulate controls of the PCCC. The flue gas quality emitted by each unit is differentiated by several factors. First, each unit has coal quality delivery targets that are slightly different, aimed at minimizing combustion issues and boiler fouling for each boiler. The wet FGD scrubbers on the units are differentiated by their oxidation state. The Unit 2 FGD operates in a natural oxidation state and the Unit 1 scrubber operates in a more inhibited state of oxidation, by design, to control corrosion in the Unit 1 2205 alloy FGD vessel. The FGD's also have differing SO2 removal efficiencies by design, with Unit 1's removal efficiency at 96-97%, (new in 2011) and Unit 2's removal efficiency at 93.5-94.5%. (retrofit of 1977 vintage FGD).

Previous aerosol testing efforts concentrated on Unit 2, since Unit 2 was the sole source of coal-derived flue gas to the PCCC considered during the FEED. That work identified cyclic patterns of particulate and sulfur loading, most probably related to operation and carryover from the FGD. The proposed sampling plan will examine particulate loading, size distribution, composition and cyclicality, both upstream and downstream of the FGD of both Unit 1 and Unit 2.

EERC proposes to use new, advanced, high resolution instrumentation, with much shorter sampling intervals than previously possible, presenting a substantial opportunity to more closely correlate plant operational factors with observed flue gas characteristics. The instrumentation includes:

- Dekati HT-ELPI+, capable of instantaneous measurement of particulate in a heated stream. This instrument can sample particulate between 6 nm and 10 μm divided into 14

size bins. The EERC uses this instrument with 10-second averaged sample intervals, giving a high degree of temporal resolution.

- Dekati DLPI, suitable for long-term particulate collection from a heated stream onto polycarbonate substrates for post-sampling laboratory analysis. Substrates from the DLPI will be brought back to the EERC to be analyzed by scanning electron microscope (SEM) and chemical analyses to determine the structure and composition of particulate matter.
- The EERC also recommends using a scanning mobility particle sizer (SMPS) to obtain high-resolution particle size distributions. The EERC's newest SMPS samples for particles in the size range of approximately 10 to 1000 nm divided into more than 100 size bins.

Other instrumentation will also be utilized. Application of this new instrumentation will improve the understanding of the mechanisms contributing to production of fine particulates that lead to aerosol formation in amine-based PCCC systems, and inform final design of particulate controls of the PCCC. Future projects incorporating multiple units with different and varying flue gas quality will benefit from the template and analysis achieved by this study. Additionally, advances in the identification of operational factors that reduce the formation pathways of aerosols will be applicable to other PCCC projects. Detailed characterization of the particulate matter upstream of the FGD will further help to assess the forms of potential aerosol precursors generated in lignite-fired boilers. These aerosol precursors are expected to be substantially different from those that have been well-characterized in the literature from higher-sulfur coals, and the results of this study may help to guide selection of aerosol minimization technologies specific to alkali-rich lignite.

Task 4 – Evaluation of Specific Value Engineering and Cost Reduction Opportunities for PCCC Facilities.

The Tundra Front End Engineering Design (FEED) study performed by Fluor from April 2020 through December 2021 (final report pending) identified over 70 potential value engineering and cost reduction opportunities in addition to the steam extraction opportunity described in Task 2 above. Some of these are Tundra specific, however a number of these tasks have been identified as potential value engineering and cost reduction opportunities that others could apply in implementation of a PCCC. The entire list of potential value engineering and cost reduction items identified is estimated to have the potential to reduce the PCCC portion of project cost by an estimated $100 million to $350 million dollars. The value of the identified cost reduction opportunities is based on a Relative Order of Magnitude (ROM) estimating approach because only preliminary design and estimating work has been done. In order to fully evaluate the technical, operational, and commercial impacts of the cost reduction items that will benefit all PCCC projects, it will be necessary to complete additional design, engineering, and evaluations of operational impacts, along with performing value estimating.

This task will evaluate the feasibility of the value engineering and potential cost reduction opportunities that are applicable to all PCCC projects and estimate the actual cost reduction potential of each.

Task 5 – Analysis of the Potential Impacts of Flue Gas Ductwork Pressure Transients When Treating Flue Gas from Single or Multiple Lignite Fired Boilers under Various Operating Scenarios.

As described above, flue gas from both Unit 2 and Unit 1 will be mixed prior to introduction into the PCCC for processing. In the base case (with extraction steam) the PCCC design capacity will be used to process 100% of the flue gas from Unit 2 and a portion of flue gas from Unit 1. Although the ability to mix the flue gases from both Unit 2 and Unit 1 will require additional emissions monitoring equipment for proper accounting, it will provide the opportunity for great flexibility in MRY operations. The flue gas systems in the MRY facility and the PCCC include several large horsepower fans that have the potential to damage the flue gas ductwork during transient conditions. This will require the design of protection systems that will prevent over pressure or under pressure in the ductwork system in all potential operating scenarios including cases where only one unit is running. The ductwork protection system will need to coordinate the operation of all fans, ductwork dampers, and protection devices in both the PCCC and the existing MRY facility.

The first step in this task will be to create a computer model of the ductwork, damper, and fans in the entire system to evaluate many possible operating and upset condition scenarios. In this task we will also identify ductwork protection requirements, create specifications, and write a detailed protection system description, and produce cost estimates which can then be used by multiple project design disciplines.

The results of this study will be important and useful to other PCCC installations at generating stations.

Task 6 – Absorber, Absorber Stack Damper, CO2 Vent System and Cooling Tower Icing Studies and Evaluation of Heat Tracing Requirements and Cold Weather Protection Requirements.

The location of the MRY station provides unique and severe seasonal variations in weather that must be addressed in the detailed design of the PCCC. The use of wet FGD scrubbers on both units at MRY upstream of the PCCC, and then a wet polishing scrubber (Direct Contact Cooler) in the PCCC, will result in a flue gas stream that will be cooled and saturated with respect to moisture as it exits the top of the absorber through the vent stack. The saturated flue gas presents significant design challenges to ensure safe operation in cold weather. In cold weather, the saturated flue gas has the potential to form ice on the vent stack, as well as on cold structures adjacent to the cooling tower. This potential for icing has significant structural consequences that must be addressed in design. In addition, there are safety of personnel and safety of operations concerns due to the potential for large quantities of ice to build up and fall from height, resulting in safety concerns and damage to equipment concerns. Further, modifying the flue gas flow rate through the current MRY chimneys could also result in new icing concerns, with the same consequences.

This task will result in a plant icing model, develop detailed requirements and cost estimates for cold weather operation of a PCCC absorber, absorber stack vent, CO_2 vent system, cooling tower, the current MRY chimneys at reduced flue gas flows, and common areas of the PCCC. The recommended mitigation strategies will be provided.

Task 7 – Evaluation of Operational Safety Using Gaseous Dispersion Modeling for Various Operating Scenarios and Emergency Conditions

The change in steam supply to the PCCC from natural gas boilers to steam extraction changes the characteristics of flue gas emissions from the PCCC and will result in rearrangement of many of the large structures. These changes require that safety of operations during various operating scenarios and emergency conditions be re-evaluated to assure that operational safety is maintained. Gaseous dispersion modeling under various weather conditions and operation scenarios is the best method to evaluate the behavior of gases vented from various locations in the PCCC.

This task will develop and evaluate gaseous dispersion models for the new flue gas characteristics and CO_2 emissions points at various weather and operating conditions. The interaction with the existing chimneys under reduced flow conditions will also be evaluated.

Task 8 – Development of Project Contract Technical Templates to Define PCCC Construction Scope of Work, Project Specifications, Guarantees, and Testing Requirements

With the completion of the FEED (final report pending) there is a well-developed set of designs and specifications for Project Tundra. In order to move into the construction phase, those designs and specifications must be translated into project-specific documents that describe in detail what the EPC contractor will build and how they will build it. These documents include: scope of work, project specifications, milestone schedules, subcontractor documents, operating manuals, startup procedures, guarantees, performance standards, and testing requirements.

This task will develop project-specific documents that conform to and describe the specific project requirements forming the basis of a "ready for execution" construction agreement. From that work a "template" EPC contract for the construction of a PCCC will be created that will assist other plant owners in the planning and development of their PCCC projects.

Project Contingency

A contingency has been set aside in the project budget. All cost line items in the Project Budget were derived from indicative estimates provided by vendors or developed using in-house estimating methodologies.

Resources

Industry sponsor and overall project manager, Minnkota Power, will provide project coordination, administration, and project advisory services. A team of industry experts will perform all project activities including the PCCC technology provider, Fluor, and owner's engineer, Sargent & Lundy.

Techniques

The primary technique for data generation under this project will be to use industry standard design and costing techniques for firm EPC proposal-level efforts. The individuals on the Project Tundra team represent decades of experience in carbon capture, and operation of coal-fired power plants.

ENVIRONMENTAL AND ECONOMIC IMPACT

The environmental impact during the period of performance of the project that is the subject of this grant request will be minimal because no experimental activities are anticipated and only

noninvasive observations and sampling activities are planned. The long-term incentive for this project comes from providing technology solutions to North Dakota's lignite industry. This industry currently has a $3.5 billion direct economic impact on the state, and preservation of the existing fleet is a top priority for the state and the lignite industry. Large-scale PCCC has tremendous potential to ensure viability of the lignite industry, since it results in reliable low-carbon base load energy, Large-scale PCCC places North Dakota in a leadership position on the development and deployment of technological solutions for carbon.

PROJECT JUSTIFICATION

These project tasks will result in a firm EPC proposal-level cost for installing PCCC on the MRY Station along with the critical information needed to support the business case for carbon capture, thereby providing a model for retrofitting PCCC on the current fleet of lignite-fired power plants in the state. Investing in this project is important to advance the state's carbon neutral goal. An additional positive outcome of Project Tundra moving forward is the creation of a pathway to keep current tax revenue and bridge for new job development. Project Tundra will develop a cost-effective way to use lignite in a carbon-managed world, supporting the premise upon which the entire lignite industry is built, namely, the sustainable combustion of lignite for power production.

STANDARDS OF SUCCESS

This project will reduce the technological and economic risks associated with investing in a PCCC system for lignite coal. It is a continuing step of measured due diligence to determine if retrofitting the existing fleet of lignite-fired power plants with PCCC technology is economically viable. Successful outcomes for the project include a firm project price that will allow Project Tundra to achieve financing and start the construction phase, while providing the electric

industry valuable information on planning and design of PCCC projects on generating units using lignite coal.

QUALIFICATIONS

Minnkota Power Cooperative Team

Minnkota will be the prime contractor for this project. Minnkota is a regional generation and transmission cooperative that supplies power to 11 member–owner distribution cooperatives across 34,500 square miles of North Dakota and Minnesota. Minnkota also serves as operating agent for the Northern Municipal Power Agency (NMPA). Headquartered in Thief River Falls, Minnesota, NMPA supplies the electric needs of 12 associated municipals that serve more than 15,000 consumer accounts in the same geographic area as the Minnkota member–owners. Minnkota brings expertise and insight into the regulatory acceptance of the coal industry along with in-kind cost-share contributions. Minnkota will play a crucial role in the project by providing vital information regarding the MRY facility, actively participating in design, and providing the host site for the project. Specific information provided will consist of process flows, available utilities, plant drawings, permit information, and gas compositions. The principal investigator from Minnkota will be Craig Bleth who will provide experienced management and leadership and be responsible for the overall success of the project. Mr. Bleth will ensure each member of the project team completes their assigned tasks, complies with all scheduling and budgetary requirements, communicates properly with all other team members, and provides necessary information to meet all reporting requirements.

EERC Team

The EERC is one of the world's major energy and environmental research organizations. Since its founding in 1951, the EERC has conducted research, testing, and evaluation of fuels,

combustion and gasification technologies, emission control technologies, ash use and disposal, analytical methods, groundwater, waste-to-energy systems, and advanced environmental control systems. Today's energy and environmental research needs typically require the expertise of a total-systems team that can focus on technical details while retaining a broad perspective.

Mr. Jason Laumb, Director of Advanced Energy Systems Initiatives, will be the overall project lead from the EERC. Mr. Laumb will focus on ensuring the overall success of the project by providing experienced management and leadership. He will be responsible for general oversight of EERC project tasks, and project reporting and administrative activities.

Mr. Joshua Strege, Assistant Director for Energy Systems, will provide experienced leadership over the flue gas testing portion of the project, ensuring the objectives of the testing program will be carried out and that project reports are prompt and of high quality.

Fluor Corporation

Fluor provides process technology and project-management solutions for chemical and petrochemical projects around the world, with a proven record of managing multi-billion-dollar projects. Fluor offers complete engineering, procurement, and construction (EPC) solutions for carbon capture projects, including CO_2 compression and transportation. Their carbon capture project experts deliver innovative, reliable, and cost-efficient project solutions such as the Econamine FG Plus^{SM} technology which is designed for energy-efficient and cost-effective CO_2 capture from low-pressure, oxygen-containing flue gas from units such as lignite-fueled boilers. Mr. James Ticer, Vice President, will serve as the project manager and brings over 30 years of engineering and construction management experience to the project.

Sargent & Lundy Team

As owner's engineer, Sargent & Lundy will oversee those portions of the project that fall outside Fluor's scope. Sargent & Lundy is a 125 year-old full-service engineering, architecture, environmental, and consulting solutions firm, based in Chicago, Illinois. Sargent & Lundy's staff of 2500 includes engineers, architects, construction professionals, planners, estimators, economists, technicians, and scientists representing virtually all design disciplines. Sargent & Lundy is involved in the design, permitting, construction, and management of facilities all over the world.

Mr. Brian Faga, Sr. Project Manager with Sargent & Lundy, will be responsible for all Sargent & Lundy activities on this project. Mr. Faga will be a key contact with the Project Tundra team and will be responsible for the balance of plant portions of the project.

David Greeson Consulting LLC

Mr. David Greeson is a consultant to the carbon capture and power generation industries. Until his retirement in 2018, Mr. Greeson was the Vice President of Development for NRG Energy and led NRG's Gulf Coast business development group and the company's carbon capture program. Mr. Greeson was the developer of the $1 billion Petra Nova Carbon Capture and Enhanced Oil Recovery project from inception through commissioning. Mr. Greeson began his career in the power industry at Houston Lighting & Power more than 40 years ago. Over those years he developed five major power projects which represent over $3 billion of investment.

Hunt International Energy Services, LLC

Mr. Marion Cole is a principal with Hunt International Energy Services, LLC an independent energy industry consulting firm established in April 1999. Mr. Cole has over forty years of

experience in power systems engineering, operations, and consulting. His expertise in the power and pipeline sectors with U.S. and international clients will help guide the CREST study process to produce results on time and on budget. Mr. Cole has led project development (gas, coal, solar and other renewable technologies), managed construction projects, negotiated numerous EPC contract, and supported startup and commissioning activities.

MANAGEMENT

Minnkota Power will serve as the lead organization for this project with Mr. Craig Bleth as the overall project manager. Mr. Bleth will ensure the overall success of this project by providing experienced management and leadership to all activities within the project. As project manager, Mr. Bleth will be responsible for the project being carried out within budget, schedule, and scope; he will also be responsible for effective communication between all project partners and Minnkota project personnel. Resumes of key personnel are included in Appendix D.

Once the project is initiated, the project team will engage in weekly conference calls to review project status and future directions. Quarterly reports will be prepared and submitted to project sponsors for review. Regular meetings will be held to review the status and results of the project and discuss directions for future work. A broad team approach is key to successful execution of this project.

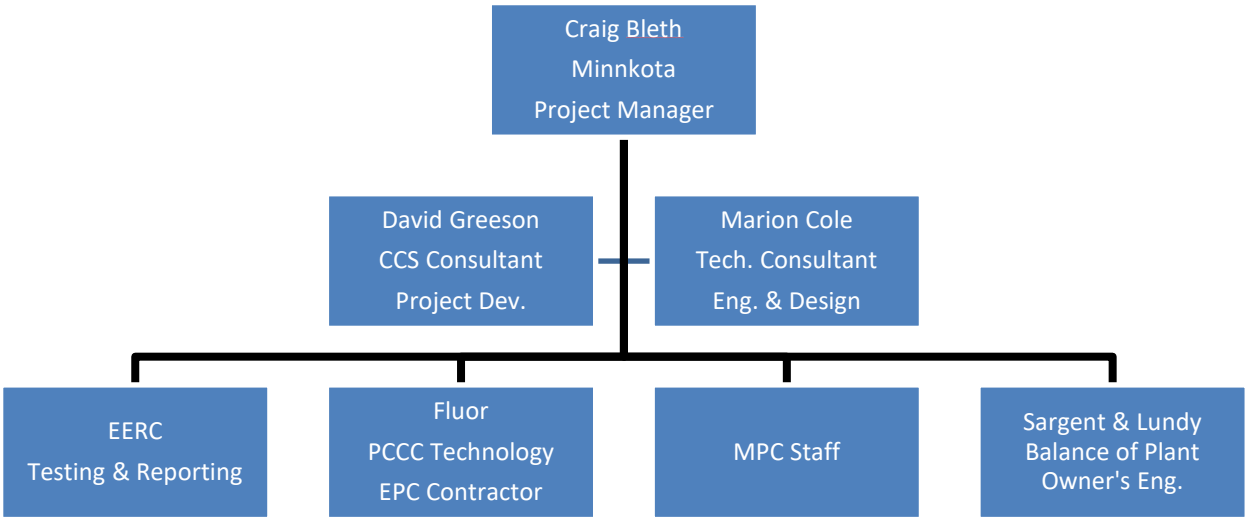

Figure 8. Simplified project management structure.

TIMETABLE AND DELIVERABLES

A timeline for the project activities is shown in Figure 9. The project anticipated start date is March 1, 2022, with a task completion date of November 1, 2022, thus resulting in a 8-month period of performance for Project Tundra CREST. The primary deliverable will be a final report completed by December 31, 2022 that will summarize the results of the tasks described in the Scope of Work section.

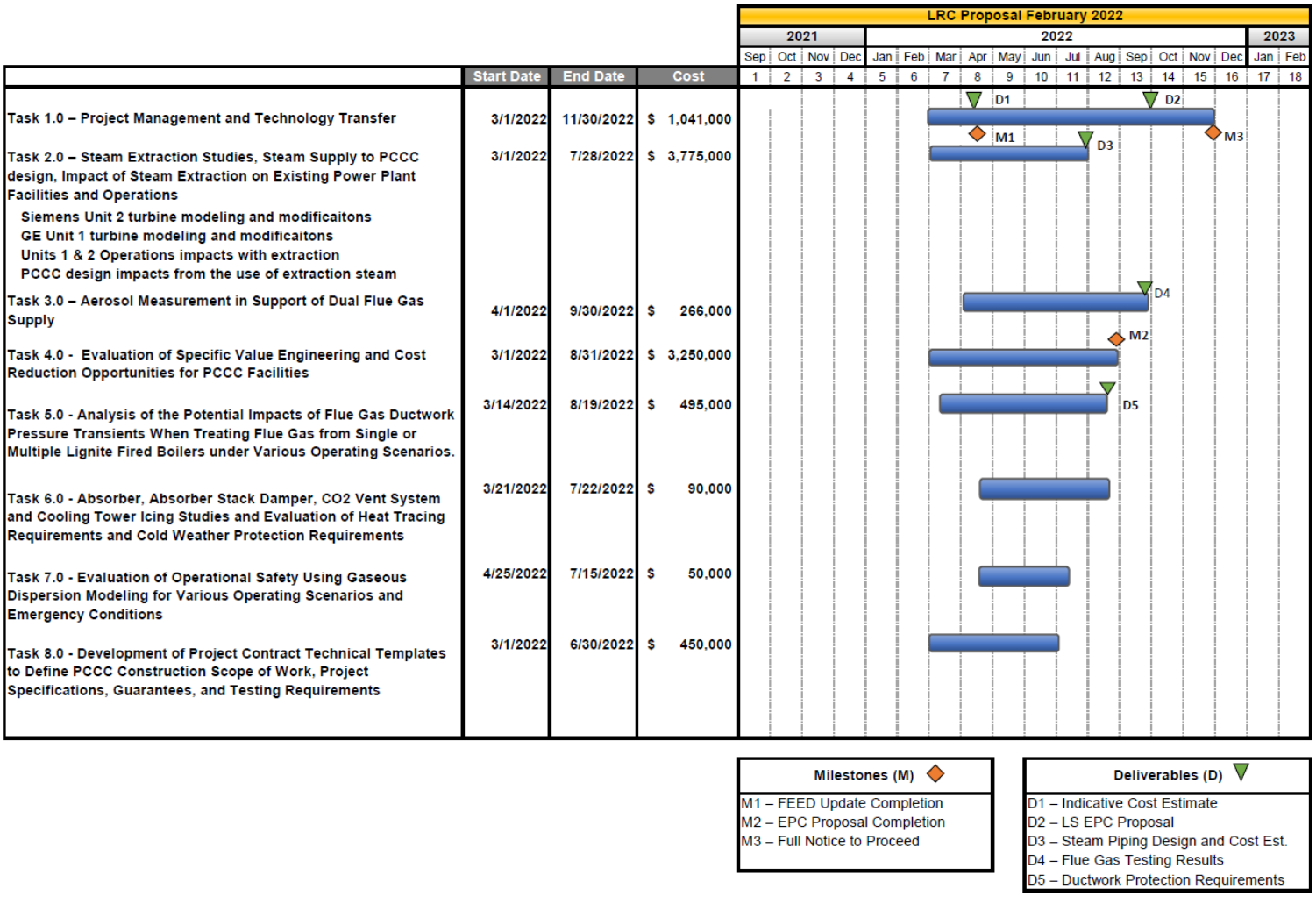

Figure 9. Simplified project schedule and milestones for Project Tundra FEED.

BUDGET

The proposed budget is $10,830,000 as shown in Table 1. This proposal requests $5,415,000 from NDIC. Minnkota will provide $4,915,000 in the form of cash and Fluor will provide $500,000 in the form of cash.

Table 1. Project Budget

Project Associated Expense	NDIC Share (Cash) ($000)	MPC Share (Cash)($000)	Fluor Share (Cash)($000)	Total Project ($000)
Task 1 – Project Management and Technology Transfer	$ 521	$ 521		$ 1,041
Task 2 – Steam Extraction Studies, Steam Supply to PCCC design, Impact of Steam Extraction on Existing Power Plant Facilities and Operations	$ 1,888	$ 1,638	$ 250	$ 3,775
Task 3 – Aerosol Measurement in Support of Dual Flue Gas Supply	$ 133	$ 133		$ 266
Task 4 – Evaluation of Specific Value Engineering and Cost Reduction Opportunities for PCCC Facilities	$ 1,625	$ 1,375	$ 250	$ 3,250
Task 5 – Analysis of the Potential Impacts of Flue Gas Ductwork Pressure Transients When Treating Flue Gas from Single or Multiple Lignite Fired Boilers under Various Operating Scenarios.	$ 248	$ 248		$ 495
Task 6 – Absorber, Absorber Stack Damper, CO2 Vent System and Cooling Tower Icing Studies and Evaluation of Heat Tracing Requirements and Cold Weather Protection Requirements.	$ 45	$ 45		$ 90
Task 7 – Evaluation of Operational Safety Using Gaseous Dispersion Modeling for Various Operating Scenarios and Emergency Conditions	$ 25	$ 25		$ 50
Task 8 –Development of Project Contract Technical Templates to Define PCCC Construction Scope of Work, Project Specifications, Guarantees, and Testing Requirements	$ 225	$ 225		$ 450
Total of Tasks Above	$ 4,709	$ 4,209	$ 500	$ 9,417
Contingency (10%)	$ 471	$ 471		$ 942
Facilities & Administration (5%)	$ 235	$ 235		$ 471
Total Project Costs	$ 5,415	$ 4,915	$ 500	$ 10,830

TAX LIABILITY

Minnkota Power is not a taxable entity; therefore, it has no tax liability.

REQUEST FOR CONFIDENTIAL INFORMATION PURSUANT TO NDCC §54-63-02

Minnkota Power, with request of partial financial support from the NDIC Lignite Research Program, is proposing to perform the CREST study for retrofit and optimization of postcombustion CO_2 capture technology at the MRY facility in North Dakota. The proposed project will include detailed engineering/costing analysis of technology provided by Fluor.

Minnkota Power requests that this information remain confidential and outside of the public domain.

APPENDIX A

LETTERS OF SUPPORT AND LETTERS OF COMMITMENT

Minnkota Power COOPERATIVE
A Touchstone Energy® Cooperative

5301 32nd Ave S
Grand Forks, ND 58201-3312
Phone 701.795.4000
www.minnkota.com

February 1, 2022

Ms. Karlene Fine
Executive Director
ATTN: Lignite Research Development and Marketing Program
North Dakota Industrial Commission
State Capitol, 14th Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Subject: Project Tundra "CREST Study"

Dear Ms. Fine:

On behalf of Minnkota Power Cooperative, I'm writing to express our support for the Project Tundra "CREST Study" proposal that is being submitted to the North Dakota Industrial Commission (NDIC).

As a company that has operated for more than 80 years in North Dakota, Minnkota is keenly focused on continuing its proud tradition of providing safe, reliable, affordable and environmentally responsible power. As the energy industry continues to go through rapid change, there is a recognition that innovation is the key to future success. For Minnkota, there is no bigger effort in this space than Project Tundra, which aims to capture and safely store 4 million metric tons of CO2 annually from the Milton R. Young Station near Center, N.D.

The advancement of Project Tundra helps position North Dakota as a leader in the development and deployment of technologies to manage CO2. Retrofitting lignite facilities with these systems represents an opportunity to preserve jobs, ensure dependable power remains on the grid and continues to make progress toward the state's carbon neutrality goal.

The work outlined in this proposal is essential to finishing Project Tundra's engineering work and provide pricing and terms for potential construction. In the process, data will be gathered that will help other carbon capture projects, including cold climate construction and design,

large-scale steam extraction from a lignite facility and other challenges in developing industry-leading technologies.

Minnkota and its project partners are committed to Project Tundra and will fund 50% of the study work, along with the proposed $5,415,000 from the Lignite Research Fund.

We have confidence that NDIC can support this project, as there is a significant need for development of postcombustion carbon capture on lignite-based facilities in North Dakota.

Again, we express our support of the proposal and look forward to working together to help bring Project Tundra closer to the finish line, while providing vital information for future technology development efforts.

Sincerely,

Mac McLennan
President & CEO

EERC
Energy & Environmental Research Center
15 North 23rd Street, Stop 9018 • Grand Forks, ND 58202-9018 • P. 701.777.5000 • F. 701.777.5181
www.undeerc.org

February 2, 2022

Mr. Craig Bleth
Senior Manager of Power Production
Minnkota Power Cooperative
Milton R. Young Station
3401 24th Street Southwest
Center, ND 58530

Dear Mr. Bleth:

Subject: Minnkota Power Cooperative Proposal: "Project Tundra CREST Study"

On behalf of the Energy & Environmental Research Center (EERC), I would like to express our commitment to the subject proposal being sent by Minnkota Power to the North Dakota Industrial Commission (NDIC), through the Lignite Research Program, as they pave theway to a secure baseload, low-carbon power. The EERC has worked successfully with industry to develop the technologies necessary for postcombustion CO_2 capture, utilization, and storage (CCUS). The EERC strongly believes that CCUS is a key step in ensuring lignite will remain animportant resource to meet the future energy needs of the United States and the world.

Should this project be accepted for award, the EERC stands ready to provide over 70 years of experience in developing, demonstrating, and commercializing clean and efficient energy technologies. Our long history of teaming with industry and government is key to developing thescientific and engineering understanding required to move energy technologies forward into the marketplace. This understanding is critical to building acceptance by both industry and the publicfor future CCUS efforts.

We have confidence that NIDC can support this activity as the next step on the development of CO_2 capture and storage at the Milton R. Young Station. The EERC looks forward to being a valuable partner in the Project Tundra demonstration facility located in NorthDakota. We are committed to working with the team to make a North Dakota-based project a reality.

DocuSigned by:
Sincerely,
Edward Steadman
AF2D5C9115E54CC...

Edward N. Steadman
Vice President for Research

BNI energy

AN ALLETE COMPANY

February 1, 2022

Mr. Craig Bleth
Senior Manager of Power Production
Minnkota Power Cooperative, Inc.
5301 32nd Avenue South
Grand Forks, ND 58201-3312

Subject: Minnkota Power Proposal "Project Tundra "CREST" Studies"

Dear Mr. Bleth:

This letter is in response to Minnkota Power Cooperative's request for support of the proposed project entitled "Project Tundra "CREST" Studies", a project proposal being submitted to the North Dakota Industrial Commission (NDIC).

BNI Energy is committed to working as an industry to advance projects that enable environmentally and economically sustainable use of North Dakota's abundant lignite resources. Project Tundra will allow for lignite production and utilization to continue, while significantly reducing CO2 emissions from the Young Station, and safely sequestering CO2 on-site.

We express our support of the proposed project, which is to conduct the final body of work necessary to bring Project Tundra to a possible start of construction by the end of 2022. We look forward to the support of NDIC, through the Lignite Research Council and the Lignite Energy Council, as this effort will complete the remaining steps in making this project a reality.

Sincerely,

Mike Heger
General Manager
BNI Coal, Ltd.

1637 Burnt Boat Drive | PO Box 897 | Bismarck, ND 58502 | 701.355.5500

APPENDIX B

RESUMES OF KEY PERSONNEL

Craig J. Bleth, PE
Senior Manager of Power Production
Minnkota Power Cooperative, Inc.
Milton R. Young Station
3401 24th Street SW, Center, ND 58530
701-794-7261, cbleth@minnkota.com

Education

University of North Dakota
B.S., Geological Engineering, 1988
B.S., Engineering Management, 1988

Professional Experience

2018-Present: Senior Manager of Power Production. Responsible for overall leadership and supervision of all departments at the Young Station. Primary role in establishing and implementing operating and financial objectives for the station. Supervise plant managers. Advocate for the plant safety objectives and ensure environmentally compliant operations. Assist and advise the President and CEO, and participate with other senior staff in corporate planning, policy setting, and decision-making.

2016-2018: Environmental Manager. Led and managed the environmental regulatory compliance efforts for the cooperative. Supervised environmental staff to achieve compliance with environmental permits and rules. Communicated environmental objectives to other departments to ensure that all activities of the cooperative met environmental requirements. Monitored and assessed pending regulations. Participated in industry groups and represented Minnkota at outside meetings. Directed Minnkota's participation in environmental research sponsorships with outside entities.

2014-2016: Plant Manager – Engineering & Environmental. Provided leadership along with daily oversight, direction, and guidance to the engineering and environmental departments at the station. Ensured key operating objectives were met in the areas of employee safety, environmental compliance, reliability, employee relations, profitability, unit availability, efficiency, and equipment, in full compliance with all applicable laws, regulations, polices, and

procedures. Provided specialized knowledge, skills, and oversight of short and long-term objectives of the plant engineering and environmental departments.

2006-2014: Plant Environmental Superintendent. Provided daily direction and guidance to the plant environmental department staff. Assisted plant leadership in ensuring achievement of key operating objectives with an emphasis on environmental compliance. From 2006 to 2022, served as the overall project manager of $244 MM in SO_2-associated air pollution control upgrades at the Young Station, including the new Unit 1 FGD scrubber, the upgraded Unit 2 FGD scrubber, new lime reagent storage and preparation facilities, replacement large-diameter outlet ductwork on both units, the new Unit 2 chimney, and the retrofit of the Unit 1 chimney.

1990-2006: Environmental Compliance Engineer Managed compliance of the solid waste program, including permitting, reporting, long-range planning and construction of facilities. Responsibility for the NDPDES and SPCC programs at the Station, including permitting and reporting. Responsibility for monitoring and inspecting Nelson Lake Dam, and was project manager of two dam repair projects. Responsible for annual SARA Tier II reporting, annual water usage reporting, and the annual EIA-767 report. Managed engineering responsibility for the Unit 2 FGD scrubber.

DAVID T. GREESON
Carbon Capture Business and Development Specialist

SUMMARY

David Greeson is an experienced expert in both carbon capture and power generation. Until 2018, David was the Vice President of Development for NRG Energy where he led NRG's Gulf Coast business development group and the company's Carbon Capture program. David developed five major projects from inception through commissioning, including the Petra Nova carbon capture and enhanced oil recovery project near Houston, TX. He is now consulting for large CO_2 emitters in the power and industrial sectors who are looking to decarbonize their products. He began his career over 40 years ago at Houston Lighting & Power Co. and held various roles primarily focused on serving and marketing to large industrial and commercial customers.

Projects Developed by David Greeson

- Petra Nova Project (NRG Energy, Inc. - 2016): David wrote the initial business plan for, and led the team that developed, permitted, financed, constructed, and placed in service the world's largest CCUS project on a power plant. The project included a US Dept. of Energy grant, buying working interest in an oilfield, purchase of a grey market combustion turbine from Saudi Arabia, construction of a cogeneration plant, bringing in two equity partners, issuance of tax-exempt bonds, and a limited recourse loan backed by Japanese export credit agencies.

- Cedar Bayou Unit 4 (NRG Energy, Inc. - 2009): A 550MW combined cycle power plant in Houston, TX that featured once-through cooling and a complex joint operating agreement with partners.

- Bighorn (Reliant Energy, Inc. - 2003) This 570MW combined cycle generator near Las Vegas, NV was built to supply a critically constrained part of the electric grid in Clark County and features dry cooling. A few years after commissioning, Nevada Energy purchased the plant and renamed it the Chuck Lenzie Station.

- Desert Basin (Reliant Energy, Inc. - 2001) Located in Casa Grande, AZ just east of Phoenix, this plant is a 600MW combined cycle project that uses municipal "gray water" for cooling. The plant serves an important grid support role in the SE Phoenix metro area and after the power purchase agreement expired with the Salt River Project, SRP purchased the plant.

- El Dorado (Reliant Energy, Inc. - 1999) El Dorado is a 480MW combined cycle project in Boulder City, NV that was developed and financed as a merchant plant.

EDUCATION

David received his BBA (Engineering Route) from University of Texas in 1980.

MARION W. COLE, P.E. (Texas)
PO Box 7567 Amarillo, TX 79114
marion@hies.com cell: 713-906-2683

SUMMARY

Marion Cole is a principal with Hunt International Energy Services, LLC an independent energy industry consulting firm established in April 1999. Mr. Cole has over forty years of experience in power systems engineering, operations and consulting. His expertise is focused on power and pipeline sectors with U.S. and international clients. Consulting services have included (but not limited to) project development (CO2 capture, gas, coal, solar and other renewable technologies) project management, EPC contract negotiation, management of third party technical resources and technology providers, HAZOP management, cost estimation, support of startup commissioning activities and resolution of power project operational issues.

PROFESSIONAL EXPERIENCE

Minnkota Power Cooperative **1/19 - Present**
Development Engineering Consultant
Currently providing technical and commercial development support for Project Tundra CCS and CO2 pipeline to CO2 storage facility. Coordination of client's in-house resources and third party engineering resources to create successful development teams and a successful CCS project.

NRG Energy, Inc. – Houston, TX **7/07 – 11/15**
Development Engineering Consultant

Provided technical and commercial support of project development activities in conventional thermal power, solar power, geothermal power, technology evaluation, carbon capture, CO_2 pipeline and enhanced oil recovery projects (EOR). Support of power facility operations, analysis of repower/redevelopment options and operational issue resolution. Coordination of client's in-house resources and third party engineering resources to create successful development teams and successful projects. Successful project development efforts included:

- **TCV CO_2 Pipeline:** 81 mile CO_2 Pipeline to deliver CO_2 from the WA Parish CCS project to the West Ranch oil field for EOR. The project is designed to deliver 1.6 million tons of CO2 annually from W.A. Parish to West Ranch
- **W.A. Parish CCS Project:** 240 MWeq Carbon Capture and Sequestration Project (CCS) currently in construction near Houston, Texas. The project is designed to remove 1.6 million tons of CO_2 annually from flue gas at W.A. Parish
- **Grid Connected Solar:** 11+ projects with total capacity in excess of 900 MW primarily located in California and Arizona. Projects included the 290 MW Agua Caliente project and the 240 MW California Valley Sun Ranch projects. Project capacities ranged from 20 MW to 290 MW
- **Cedar Bayou Unit 4:** 550 MW combined cycle facility in Chambers County, Texas.

Mann Turbines – Germany **1/12 – 6/13**
Development Engineering Consultant

- Lead the gas turbine package design for the Mann Turbine GT6 6.5 MW gas turbine generator set in support of Freeman & Curiel Engineering contract with Mann Turbines.

AltaGas – Calgary, Canada **11/11 – 1/12**
Engineering Consultant

- Provided due diligence support and operational evaluation for the acquisition of two biomass power plants.

White Energy – Australia **11/08 – 12/09**
Development Engineering Consultant

- Lead the business development effort of a coal benefaction process facility in the Powder River Basin of Wyoming. Duties included design project management, permitting, cost estimation, scheduling, economic analysis and sales support.

Kawasaki Gas Turbines – Japan **10/06 – 6/07**
Development Engineering Consultant

- Lead the gas turbine package design for three Kawasaki Gas Turbine generator packages for sale in the US market and to Oil and Gas (API) customers in support of Freeman & Curiel Engineering contract with Kawasaki.

Enron Corp. – Houston, TX **3/98 – 4/00**
Vice President, Enron Renewable Energy Corporation
Member, Board of Directors of Enron Wind Corp.

Responsibilities included technology review, business development, performance estimation and design engineering for Enron Renewable Energy Corporation.

- Provided technical and commercial due diligence during the acquisition of Zond Systems Corporation and Tacke GmbH (wind companies) that later became GE Wind
- Developed hydroelectric project opportunities in Nepal, Brazil, the Philippines, China, Guatemala and North America
- Responsible for assessment of geothermal project opportunities in North America, Indonesia and China
- Served as Vice President of Amoco/Enron Solar, a joint venture that later became part of BP Solar.

Enron Corp. – Houston, TX **3/89 – 3/98**
Director Development Engineering, Enron Power Corp.

Responsible for international power and infrastructure business development and development engineering. Responsibilities included conceptual design of power facilities, project development and support, structuring of project execution teams, contract negotiations, due diligence of international project sites, partners and suppliers, permitting and management of outside consultants.

- Directed the design of Enron's first international power project; the 1,800MW Teesside power project in the United Kingdom
- Provided technical interface to the U.K. National Grid Company, financing institutions, project partners and permitting authorities
- Successful projects in North America, the United Kingdom, Puerto Rico, Turkey, Brazil, India, Guatemala, the Philippines and other locations.

Stewart and Stevenson Services, Inc. - Houston, TX **3/81 – 1/89**
Director Development Engineering & Development

Recruited from Pratt and Whitney Aircraft by Stewart and Stevenson Services, Inc. to develop a gas turbine power business. Responsible for all gas turbine design engineering including gas turbine package design, technical support of sales, performance estimation, project economic analysis, equipment selection, performance testing, field startup and commissioning.

- Developed highly successful lines of gas turbine power generation packages (LM 2500, LM 5000 and LM 6000) that continue as the core of GE Aero Engine business
- Grew gas turbine business from $700k annually to $680 million annually prior to sale of company to GE.

Pratt and Whitney Aircraft – West Palm Beach, FL **9/79 – 2/81**
Aircraft Integration and Test Engineer

Performance Test Engineer for military aircraft gas turbine engines. Assignments included:

- Field engine problem resolution at U.S. Military installations worldwide for the F-14, F-15 and F-16 aircraft
- Designed a military engine performance test facility, designed for integration of new development engine in aircraft prototype aircraft
- Evaluated combustion systems, fuel systems, control systems design and modifications to reduce emissions and increase performance.

Education & Certifications

Bachelor of Mechanical Engineering: University of Texas, Austin TX - 1979
Registered Professional Engineer: Texas
DOD Security Clearance – lapsed.

JASON D. LAUMB
Director of Advanced Energy Systems Initiatives
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, ND 58202-9018 USA
701.777.5114 (phone), 701.777.5181 (fax), jlaumb@undeerc.org

Principal Areas of Expertise

Mr. Laumb's principal areas of interest and expertise include renewable energy, CO_2 capture, techno-economic modeling, extraction of critical materials, environmental control systems, supercritical CO_2 power cycles, and advanced gasification technologies. His experience includes biomass and fossil fuel conversion for energy production, with an emphasis on ash effects on system performance; trace element emissions and control for fossil fuel combustion systems, with a particular emphasis on air pollution issues related to mercury and fine particulates; and design and fabrication of bench- and pilot-scale combustion and gasification equipment.

Education and Training

M.S., Chemical Engineering, University of North Dakota, 2000.
B.S., Chemistry, University of North Dakota, 1998.

Research and Professional Experience

May 2021–Present: Director of Advanced Energy Systems Initiatives, EERC, UND. Mr. Laumb provides leadership on projects related to advanced energy systems and leads a multidisciplinary team of scientists and engineers working on advanced energy technologies from pollution control to new energy platforms.

September 2019–April 2021: Assistant Director of Advanced Energy Systems, EERC, UND. Mr. Laumb assisted the EERC executive team by providing leadership on projects related to advanced energy systems. Mr. Laumb led a multidisciplinary team of scientists and engineers working on advanced energy technologies from pollution control to new energy platforms. Specific areas of interest included CO_2 capture, techno-economic modeling, environmental control systems, supercritical CO_2 power cycles, and advanced gasification technologies. Research activities focused on low-carbon-intensity power cycles for fossil fuel-fired systems.

2008–August 2019: Principal Engineer, Advanced Energy Systems Group Lead, EERC, UND. Mr. Laumb led a multidisciplinary team of 30 scientists and engineers to develop and conduct projects and programs on power plant performance, environmental control systems, the fate of pollutants, computer modeling, and health issues for clients worldwide. Efforts focused on development of multiclient jointly sponsored centers or consortia funded by government and industry sources. Research activities included computer modeling of combustion/gasification and

environmental control systems, performance of SCR technologies for NO_x control, mercury control technologies, hydrogen production from coal, CO_2 capture technologies, particulate matter analysis and source apportionment, the fate of mercury in the environment, toxicology of particulate matter, and in vivo studies of mercury–selenium interactions.

2001–2008: Research Manager, EERC, UND. Mr. Laumb led projects involving bench-scale combustion testing of various fuels and wastes as well as a laboratory that performs bench-scale combustion and gasification testing. He served as principal investigator and managed projects related to the inorganic composition of coal, coal ash formation, deposition of ash in conventional and advanced power systems, and mechanisms of trace metal transformations during coal or waste conversion and wrote proposals and reports focused on energy and environmental research.

2000–2001: Research Engineer, EERC, UND. Mr. Laumb assisted in the design of pilot-scale combustion equipment and wrote computer programs to aid in the reduction of data, combustion calculations, and prediction of boiler performance. He was also involved in the analysis of combustion control technologies' ability to remove mercury and the suitability of biomass as boiler fuel.

1998–2000: SEM Applications Specialist, Microbeam Technologies, Inc., Grand Forks, North Dakota. Mr. Laumb gained experience in power system performance including conventional combustion and gasification systems; knowledge of environmental control systems and energy conversion technologies; interpreting data to predict ash behavior and fuel performance; assisting in proposal writing to clients and government agencies such as the National Science Foundation and the U.S. Department of Energy; preparing and analyzing coal, coal ash, corrosion products, and soil samples using SEM/EDS; and modifying and writing FORTRAN, C+, and Excel computer programs.

Professional Activities
Member, American Chemical Society

Publications
Mr. Laumb has coauthored numerous professional publications.

JOSHUA R. STREGE
Assistant Director for Energy Systems
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5080 (phone), 701.777.5181 (fax), jstrege@undeerc.org

Principal Areas of Expertise

Mr. Strege's principal areas of interest and expertise include biomass and fossil fuel conversion for energy production, with an emphasis on CO_2 capture and storage in power generation and in industrial applications. He is certified in Aspen Plus and Aspen HYSYS and is proficient in process modeling and techno-economic assessments. He also has significant experience in the design, fabrication, and operation of bench- and pilot-scale equipment for combustion, gasification, synthetic and renewable fuel production, and CO_2 capture.

Education and Training

M.S., Chemical Engineering, University of North Dakota, 2005. Thesis: High-Temperature Corrosion of Potential Heat Exchange Alloys under Simulated Coal Combustion Conditions.

B.S., Chemical Engineering, University of North Dakota, 2005.

Training includes project management training through PM College, Six-Sigma Green Belt, and Design Flow Technology (DFT).

Software skills include Microsoft Office suite (Excel, MS Project, Word, and Access) and advanced VBA macro programming and SQL server integration; CAD design and engineering drawing creation (PTC Creo Parametric).

Certifications include Aspen Plus- and Aspen HYSYS-certified.

Research and Professional Experience

May 2021–Present: Assistant Director for Energy Systems, EERC, UND. Mr. Strege leads a multidisciplinary team of engineers and scientists in evaluating and demonstrating energy processes from the initial modeling phase through physical testing at the bench, pilot, and demonstration scales. Specific areas of interest include CO_2 capture and transport, process modeling and techno-economic analysis, gasification and combustion technology development and demonstration, and other energy conversion technologies. Current research activities are focused on low-carbon-intensity power cycles for fossil fuel- and biomass-fired systems.

October 2019–April 2021: Principal Process Engineer, Energy Systems Development, EERC, UND. Mr. Strege led the process engineering team in process modeling and techno-economic analysis efforts across applied research projects encompassing CO_2 capture and transport, advanced power cycle technology development, and other energy conversion technologies.

2013–September 2019: Project Manager and Senior Engineer, Cirrus Aircraft. Mr. Strege's responsibilities as Project Manager included building an 80-member team to develop and manufacture composite products for small aircraft under contract with an outside client. As Senior Engineer, he led a team of engineers and technicians responsible for reducing waste, implementing root cause and corrective actions on product defects and downstream issues, and developing and implementing software solutions for improved tracking and accountability across all departments.

2005–2013: Research Engineer, EERC, UND. Mr. Strege participated in and managed several multiyear, multiclient projects aimed at researching and developing alternative energy and fuel sources. Specific projects included hydrotreating of waste vegetable oils for conversion to drop-in-compatible JP-8 jet fuel, assessing the feasibility of modern warm-gas cleanup technologies for liquid fuel synthesis via the Fischer–Tropsch process, and design and testing of cold-gas cleanup reactors for syngas. He also participated in pilot-scale studies comparing the postcombustion CO_2 capture efficiency of a variety of proprietary and conventional amine-based solvents.

2000–2005: Student Research Assistant, EERC, UND. Mr. Strege's responsibilities included design and development of instrument control software. In addition, he studied corrosion rates and mechanisms of high-temperature alloys as part of his master's research.

Publications

Mr. Strege has authored and coauthored numerous professional publications.

BRIAN A. FAGA, P.E.

Senior Manager
Energy & Industrial Group

Education

Master of Science in Biosystems Engineering – Oklahoma State University, Stillwater, OK

Bachelor of Science in Mechanical Engineering – Purdue University, West Lafayette, IN

Registrations

Licensed Professional Engineer – Illinois, Louisiana, Texas

Proficiencies

- Project and Engineering Management
- Detailed mechanical systems engineering, design, and equipment specification
- Conceptual design engineering, industrial, simple/combined cycle, coal, and biomass units
- FEED Studies
- Detailed engineering studies and cost estimates
- Technology assessment and selection
- Natural gas fuel system engineering, design, and equipment specification
- Owner's Engineer technical support, specifications, and EPC management

Sargent & Lundy Experience

Entergy

- 2021 – On-going | Project manager for a natural gas combined cycle carbon capture feasibility study to select a potential generating unit and appropriate carbon capture technology. S&L is responsible for preparing the feasibility engineering and calculations as well as evaluating the offerings of the carbon capture technology suppliers.

CLECO Power LLC

- 2021 – On-going | Project Manager for a carbon capture project that includes feasibility study to determine the cost and viability of installing a CO2 capture system and evaluation of solvent-based technology suppliers followed by a FEED study. S&L is responsible for BOP preliminary design and interconnection to support the CO2 capture system including technical and commercial evaluations.
- 2021 | Project Manager for a decarbonization study evaluating multiple technologies and approaches to reduce or eliminate carbon emissions from existing generating facilities.

- 2019 – 2021 | Project Manager for two medium voltage switchgear replacement projects. S&L prepared technical procurement specifications and prepared BOP engineering to integrate the replacement equipment into the existing facility.
- 2015 – 2019 | Owner's Engineer project manager for a 50 MW heat recovery steam generator and steam turbine power generation facility. Provided permitting support, cost estimates, specifications for all major equipment, reviewed the detailed design, prepared installation contractor specifications, and provided startup/commissioning services.
- 2015 – 2021 | Various plant betterment projects across fleet of combined cycle, natural gas, and coal fired stations, including condition assessments, environmental studies, equipment upgrades/replacements, cost estimates, equipment specifications, and detailed designs.
- 2017 – 2018 | Project manager for front end engineering and design (FEED) for potential conversion of a 600 MW coal fired boiler to natural gas. Interfaced with boiler OEMs for performance and environmental impacts. Provided detailed design for detailed capital and O&M cost estimates.

NRG Energy Inc.

- 2021 – On-going | Project manager for restoration engineering and procurement support of a wet FGD process area and flue gas ductwork for a large coal-fired unit.
- 2019 – On-going | Project manager for consulting services related to CCR and ELG rule compliance across fleetwide generating facilities.
- 2018 – On-going | Project manager for periodic structural and walking surface examinations across multiple fleetwide generating facilities. Included development and refinement of Owner's examination standards.
- 2018 | Project manager for detailed design and material/installation specification for a steel sheet pile flood protection wall to fully surround a combined cycle facility to protect from flooding.
- 2017 | Project manager for detailed engineering, design, and procurement specifications to add a water distillation and reverse osmosis facility to an existing combined cycle / co-gen facility in order to make salable distilled water for industrial users.
- 2013 | Mechanical lead on the procurement, design, and installation of selective non-catalytic reduction (SNCR) and water treatment systems for three 600 MW coal units at Big Cajun II as part of the Southwest Region MATS compliance projects.
- 2012 – 2013 | Mechanical lead on the procurement of activated carbon injection (ACI) systems for nine coal units in Texas and Louisiana as part of the Southwest Region MATS compliance projects.
- 2011 – 2012 | Supported the development of Carbon Capture and Sequestration (CCS) conceptual designs at the W. A. Parish Generating Station for 60 MW and 240 MW flue gas slipstreams. Developed conceptual design, combustion turbine and HRSG selection for system power and steam supply, general arrangements, process flow diagrams, equipment and pipe sizing, auxiliary power requirements, utility interface lists, and input to cost estimate.
- 2011 | Acted as mechanical lead on the preliminary design and detailed cost estimate for a 25 MW plasma gasification waste-to-energy facility including the development of project design criteria, budgetary specifications for major equipment, general arrangements, P&IDs, heat balances, water balances, material handling process flow diagrams, permitting support documents, and project schedule.
- 2011 | Developed a proposal to act as Owner's Engineer, including the development of EPC specifications, for a 700 MW combined cycle project in the northeast.

Cabot Corporation

- 2019 – 2020 | Project manager for Phase 2 Alternatives Analysis of air pollution control and energy center project for a carbon black facility in Louisiana. The project included conceptual engineering of multiple technologies, conceptual process design, major equipment specification development, project schedule development, cost estimate development, and value engineering for cost reduction.

GenOn Energy, Inc. | 2011 – 2012

- Mechanical engineer on the execution of an axial booster fan contract for a SCR installation project on two 900 MW coal units in the northeast.

J-Power USA Development Co., Ltd and Dominion | 2010 – 2011

- Feasibility study for the conversion of four simple cycle peaking 7FA combustion turbines in Illinois to two, 2x2x1 combined cycle units with the addition of HRSGs and STGs. Study included an evaluation of air cooled vs. water cooled condensing options, development of a design basis, general arrangements, system descriptions, performance estimates, water balance and makeup water supply assessment, permitting impacts, preliminary project schedule, and capital/O&M cost estimate.

Terna S.A. | 2010 – 2011

- Supported the development of a detailed EPC cost estimate for a new 660 MW lignite-fired pulverized coal unit in Greece including development of equipment list, budgetary specifications for BOP equipment, P&IDs, system descriptions, water balance and site GA.

NV Energy | 2010 – 2011

- Performed biomass supply and co-firing feasibility study for a 100 MW pulverized coal fired unit in Nevada. Study included biomass supply study from private and public sources, biomass characteristics, applicable technologies for co-firing up to 10% of unit heat input, unit impacts, emissions impacts, order of magnitude cost estimate, and preliminary test burn procedure.

Toyo Engineering Corp. | 2010

- Supported the development of a detailed EPC cost estimate for a new 170 MW lignite-fired CFB unit in Turkey including development of design basis, equipment list, P&IDs, and site GA.

Duke Engineering International | 2010

- Supported the development of a detailed EPC cost estimates for multiple simple cycle and combined cycle unit arrangements for a site in Brazil ranging from 200 to 500 MW, including development of design basis, equipment list, P&IDs, and site GA.

ecoPower Generation LLC | 2009

- Conceptual design, boiler technology selection, fuel analysis, and permitting support for a 50 MW fluidized-bed biomass unit.

PacifiCorp Energy | 2009

- Evaluation of balance-of-plant equipment including feedwater heaters and piping, steam piping, condenser, boiler feed pumps, condensate pumps, and safety valves for turbine and boiler uprate modifications at multiple plants.

Dynegy Inc.

- 2005 – 2007 | Vermilion Units 1 & 2 Fabric Filter and Activated Carbon Mercury Capture System, Service Water System Upgrades, Temporary SO3 Injection System.

- 2006 – 2007 | Units 1, 2, & 3 Flue Gas Desulphurization Project, Station Heating System Upgrade, Sootblower Installation, Instrument Air System Upgrade.
- 2006 – 2007 | Hennepin Units 1 & 2 Fabric Filter and Activated Carbon Mercury Capture System.

Southern Illinois Power Cooperative* | *2006 – 2007

- Marion Station FGD Oxidation Air System Specification and Gypsum Dewatering System Specification.

Memberships

- American Society of Mechanical Engineers (ASMEC)