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

March 30, 2021

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

Dear Ms. Fine:

Subject: EERC Proposal No. 2021-0106 Entitled "Ammonia-Based Energy Storage Technology (NH_3-BEST)"

The Energy & Environmental Research Center (EERC) is pleased to submit this cost-share funding request to the Lignite Research, Development and Marketing Program (LRDMP) for support of the NH_3-BEST project. The 1-year project has been selected for award by the U.S. Department of Energy, with an April 1, 2021, start date.

Enclosed please find an original and one copy of the subject proposal along with a check for $100. The EERC, a research organization within the University of North Dakota, an institution of higher education within the state of North Dakota, is not a taxable entity; therefore, it has no tax liability.

This transmittal letter represents a binding commitment by the EERC to complete the project described in this proposal. If you have any questions, please contact me by telephone at (701) 777-2982, by fax at (701) 777-5181, or by e-mail at taulich@undeerc.org.

Sincerely,

DocuSigned by:
Ted Aulich
89B1B8E4D0E7430...

Ted R. Aulich
Principal Process Chemist, Fuels and Chemicals

Approved by:

DocuSigned by:
Erin M. O'Leary, for
3C56131ED6AA4EE...

Charles D. Gorecki, CEO
Energy & Environmental Research Center

TRA/kal

Enclosures

UND UNIVERSITY OF NORTH DAKOTA

Lignite Research, Development and Marketing Program

North Dakota Industrial Commission

Application

Project Title: Ammonia-Based Energy Storage Technology (NH_3-BEST)

Applicant: University of North Dakota Energy & Environmental Research Center

Principal Investigator: Ted R. Aulich

Date of Application: March 30, 2021

Amount of Request: $101,390

Total Amount of Proposed Project: $426,390

Duration of Project: 12 months

Point of Contact (POC): Ted R. Aulich

POC Telephone: (701) 777-2982

POC E-Mail: taulich@undeerc.org

POC Address:

15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

TABLE OF CONTENTS

ABSTRACT

Objectives: The project will model, validate, and define a commercialization strategy for an ammonia-based energy storage technology (NH_3-BEST) tailored for North Dakota lignite-fired power plants. NH_3-BEST encompasses the three integrated unit operations of low-pressure electrolytic ammonia production, ammonia storage, and ammonia conversion to electricity in a direct ammonia fuel cell (DAFC). Refined and optimally deployed, NH_3-BEST could strengthen and expand the lignite power industry. By enabling accommodation of power demand fluctuations while steadily operating within an optimal-performance baseline power output range, NH_3-BEST would ensure maximum plant operational efficiency and minimum degradation of materials, equipment, and performance due to load cycling-driven stresses. In addition, NH_3-BEST deployment at North Dakota lignite power plants would open opportunities for expanding lignite utilization to include powering production of ammonia for regional agricultural markets. Primary project objectives are to 1) define—with input from utility partners—NH_3-BEST operational and performance targets based on plant-specific energy storage objectives; 2) using appropriate process simulation software, develop a dynamic model of the NH_3-BEST subsystem; and 3) utilize the model to evaluate and optimize NH_3-BEST performance and economics.

Expected Results: 1) Preliminary design of NH_3-BEST subsystem; 2) set of requirements for power plant–NH_3-BEST integration; 3) data needed for NH_3-BEST validation and pilot-scale demonstration at a power plant; 4) establishment of NH_3-BEST performance and cost targets to meet utility requirements for deployment; and 5) a road map for NH_3-BEST commercial deployment, describing work needed to advance to component and system-level integration engineering and validation testing, and technical and nontechnical challenges to NH_3-BEST implementation.

Duration: 12 months

Total Project Cost: $426,390

Participants: University of North Dakota Energy & Environmental Research Center (EERC), Minnkota Power Cooperative, Basin Electric Power Cooperative, Otter Tail Power Company, Vetri Labs (electrochemical energy systems developer).

PROJECT SUMMARY

Objectives: The University of North Dakota Energy & Environmental Research Center (EERC), in partnership with Minnkota Power Cooperative, Basin Electric Power Cooperative, Otter Tail Power Company, and Vetri Labs (electrochemical energy systems developer), proposes to model, validate, and define a commercialization strategy for an ammonia-based energy storage technology (NH_3-BEST) tailored for North Dakota lignite-fired power plants. Primary project objectives are to:

1) Define—with input from utility partners—NH_3-BEST operational and performance targets based on power plant-specific energy storage objectives.
2) Using appropriate process simulation software, develop a basic model of the NH_3-BEST subsystem, which comprises the three integrated unit operations of electrolytic ammonia production, ammonia storage, and ammonia conversion to electricity in a direct ammonia fuel cell (DAFC).
3) Utilize the NH_3-BEST model to:
    - Develop preliminary design of NH_3-BEST subsystem.
    - Identify necessary work to advance to component-level engineering and validation testing.
    - Define power plant system integration requirements.
    - Establish performance requirements and their relationship to cost.
    - Identify technical and nontechnical gaps to resolve for NH_3-BEST commercial deployment.
4) Demonstrate—in a lab-scale electrochemical unit cell—ammonia production using inputs of electricity, water, and air-separated nitrogen.

Methodology: NH_3-BEST encompasses integration of three unit operations—ammonia production, storage, and conversion (to electricity)—with a power plant or "electricity generation unit" (EGU). When power demand is less than baseload power output ($D < B$), excess power is diverted to NH_3-BEST, and when $D > B$, power is pulled from NH_3-BEST. The unit operations essentially comprise:

1) Ammonia production via the 1-step electrolytic ammonia (1-SEA) process. The process operates at near-ambient pressure and 300°–450°C with inputs of electricity, water, and air-separated nitrogen.

The 1-SEA process derives from the EERC-developed low-pressure electrolytic ammonia process, which uses externally produced hydrogen rather than water as anode feed.

2) Ammonia storage at ambient temperature and pressure of about 250 psi.
3) Ammonia conversion to electricity in a direct ammonia fuel cell (DAFC).

The 1-SEA anode reaction is water electrolysis, but unlike traditional electrolysis where anode-generated protons travel through electrolyte and recombine at the cathode to form elemental hydrogen, in 1-SEA, protons react at the cathode with elemental nitrogen molecules to form ammonia. Because electrolysis power/electricity consumption can be decreased by replacing electrical energy with thermal energy, NH_3-BEST technical and economic viability is premised on the hypothesis that EGU heat/steam resources can be creatively adapted and deployed to capitalize on this fact sufficiently to effect major improvements in EGU performance and economics. To prove this hypothesis, the proposed approach/methodology essentially comprises 1) building a model of NH_3-BEST, 2) using the model to simulate and optimize NH_3-BEST integration with a commercially operating EGU, and 3) using model outputs—along with utility partner-provided data and information—to demonstrate ease of EGU–NH_3-BEST integration and quantify EGU cost and performance benefits. In addition, to further support NH_3-BEST commercial viability, the project will include lab-scale demonstration of the 1-SEA process–ammonia production using inputs of electricity, water, and air.

Project Work Scope: The work scope will define and build (using Aspen process simulation software) a basic model of the NH_3-BEST concept/subsystem comprising 1) electrolytic ammonia production, 2) ammonia storage, and 3) ammonia conversion to electricity via a direct ammonia fuel cell (DAFC). The basic model will be tailored for application to the energy storage scenarios developed for each utility and used to assess NH_3-BEST impacts on utility performance and economics. Additional work includes demonstration of ammonia synthesis from electricity, water, and air-separated nitrogen (the 1-SEA process) and networking to advance NH_3-BEST toward commercial deployment. Proposed tasks are described below.

Task 1 – Project Management – Month 1 – Month 12 (M1–M12) – Task 1 encompasses all activities related to project direction, communication with all technical and nontechnical participants, and meeting all reporting and deliverable requirements.

Task 2 – Define NH_3-BEST – M1–M6 – Utility-provided EGU load-cycling and other relevant data and information will be utilized to define 1) NH_3-BEST operational (power output) range, 2) minimum energy storage requirement (in MWs), and 3) energy storage duration range. The EERC team will then define the operating parameters and performance metrics for the NH_3-BEST to fulfill the energy storage needs.

Task 3 – Build Basic Model of NH_3-BEST – M1–M6 – Aspen HYSYS, an industrial process modeling and simulation package, will be used to create a basic NH_3-BEST model based on process boundary conditions and parameters identified in Task 2.

Task 4 – Evaluate NH_3-BEST Performance and Economics – M4–M12 – The basic NH_3-BEST model will be tailored as needed for application to each utility's energy storage scenario and used to assess and optimize performance and economic impacts.

Task 5 – Complete R&D for 1-SEA Process Proof-of-Concept Validation – M4–M12 – Ammonia production using inputs of electricity, water, and nitrogen will be demonstrated using a ≥25-cm^2 membrane–electrode assembly comprising an EERC-developed 300°C-capable proton exchange membrane and selected anode and cathode catalysts.

Task 6 – Network with Industrial Technology Developers and End Users – M1–M12 – Progress and findings will be communicated with project utility partners and other potential end users (as approved by utility partners) with the goal of building a team and securing funding for NH_3-BEST pilot-scale demonstration at a working power plant.

Anticipated Results: Anticipated results include the following:

- Preliminary design of NH_3-BEST subsystem.
- Defined set of requirements for power plant–NH_3-BEST integration.

- Establishment of NH_3-BEST performance and cost targets to meet utility requirements for deployment.
- Identification of necessary work to advance to component-level engineering and validation testing (to be documented in a separate "technology maturation plan/commercialization strategy" deliverable).
- Identification of technical and nontechnical gaps to resolve for NH_3-BEST commercial deployment.
- Demonstration of the 1-SEA process (ammonia synthesis from electricity, water, and air-separated nitrogen).

PROJECT DESCRIPTION

Objectives: The University of North Dakota Energy & Environmental Research Center (EERC), in partnership with Minnkota Power Cooperative, Basin Electric Power Cooperative, Otter Tail Power Company, and Vetri Labs (electrochemical energy systems developer), proposes to model, validate, and define a commercialization strategy for an ammonia-based energy storage technology (NH_3-BEST) tailored for North Dakota lignite-fired power plants. NH_3-BEST is built around the use of excess electricity to produce ammonia—long-valued as fertilizer and increasingly valued as an energy carrier/fuel. Refined and optimally deployed, NH_3-BEST could strengthen and expand the lignite power industry. By enabling accommodation of power demand fluctuations while steadily operating within an optimal-performance baseline power output range, NH_3-BEST would ensure maximum plant operational efficiency and minimum degradation of materials, equipment, and performance due to load cycling-driven stresses. In addition, NH_3-BEST deployment at North Dakota lignite power plants would open opportunities for expanding lignite utilization to include powering production of ammonia for regional agricultural markets. Primary project objectives are to:

1) Define—with input from utility partners—NH_3-BEST operational and performance targets based on EGU energy storage objectives.

2) Using appropriate process simulation software, develop a basic model of the NH_3-BEST subsystem, which comprises the three integrated unit operations of electrolytic ammonia production, ammonia storage, and ammonia conversion to electricity in DAFC.
3) Utilize the NH_3-BEST model to:
   - Develop preliminary design of NH_3-BEST subsystem.
   - Identify necessary work to advance to component-level engineering and validation testing.
   - Define power plant system integration requirements.
   - Establish performance requirements and their relationship to cost.
   - Identify technical and nontechnical gaps to resolve for NH_3-BEST commercial deployment.
4) Demonstrate—in a lab-scale electrochemical unit cell—ammonia production using inputs of electricity, water, and air-separated nitrogen.

Methodology: As depicted in Figure 1, NH_3-BEST encompasses integration of three unit operations—ammonia production, storage, and conversion (to electricity)—with an EGU. When demand is less than baseline ($D < B$), excess power is diverted to NH_3-BEST, and when $D > B$, power is pulled from NH_3-BEST. Unit operations essentially comprise:

1) Ammonia production via the 1-step electrolytic ammonia (1-SEA) process. The process operates at near-ambient pressure and 300°–450°C with inputs of electricity, water, and air-separated nitrogen, as shown in Figure 2. The 1-SEA process derives from the EERC-developed low-pressure electrolytic ammonia process, which uses externally produced hydrogen rather than water as anode feed.
2) Ammonia storage at ambient temperature and pressure of about 250 psi.
3) Ammonia conversion to electricity in a DAFC, as shown in Figure 2.

As shown in Figure 2, the 1-SEA anode reaction is water electrolysis, but unlike traditional electrolysis where anode-generated protons travel through the electrolyte and recombine at the cathode to form elemental hydrogen, in 1-SEA, protons react at the cathode with elemental nitrogen molecules to

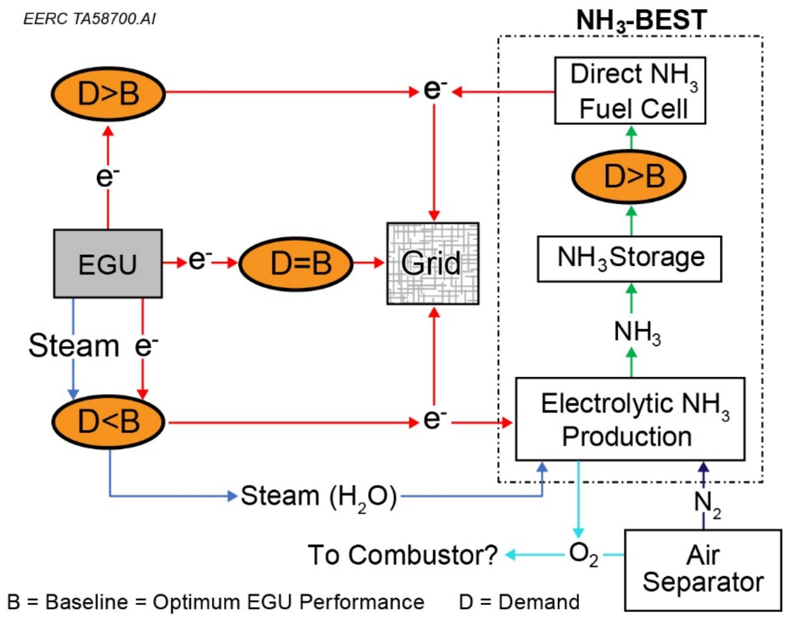

Figure 1. NH_3-BEST integrated with EGU.

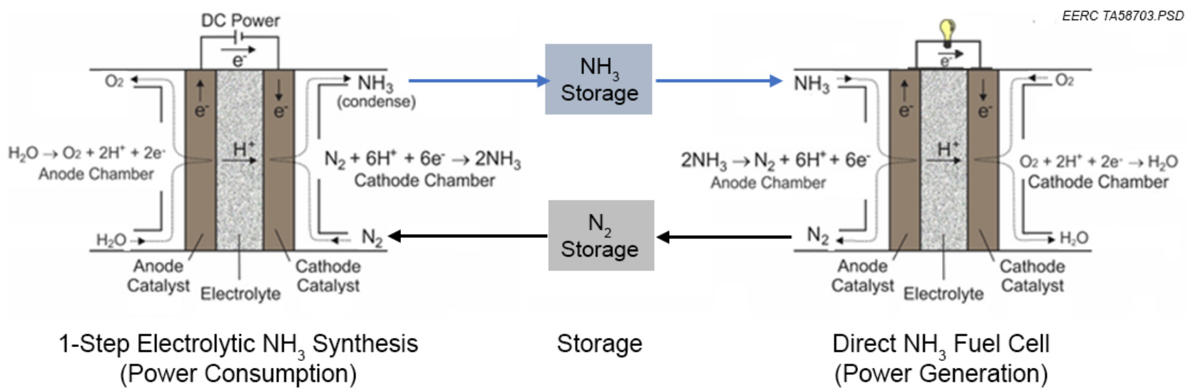

Figure 2. NH_3-BEST unit operations.

form ammonia. As shown in Figure 3, electrolysis power/electricity consumption can be decreased by replacing electrical energy with thermal energy. NH_3-BEST technical and economic viability is premised on the hypothesis that EGU heat/steam resources can be creatively adapted and deployed to capitalize on this fact sufficiently to effect major improvements in EGU performance and economics. To prove this hypothesis, the proposed approach/methodology essentially comprises 1) building a model of NH_3-BEST,

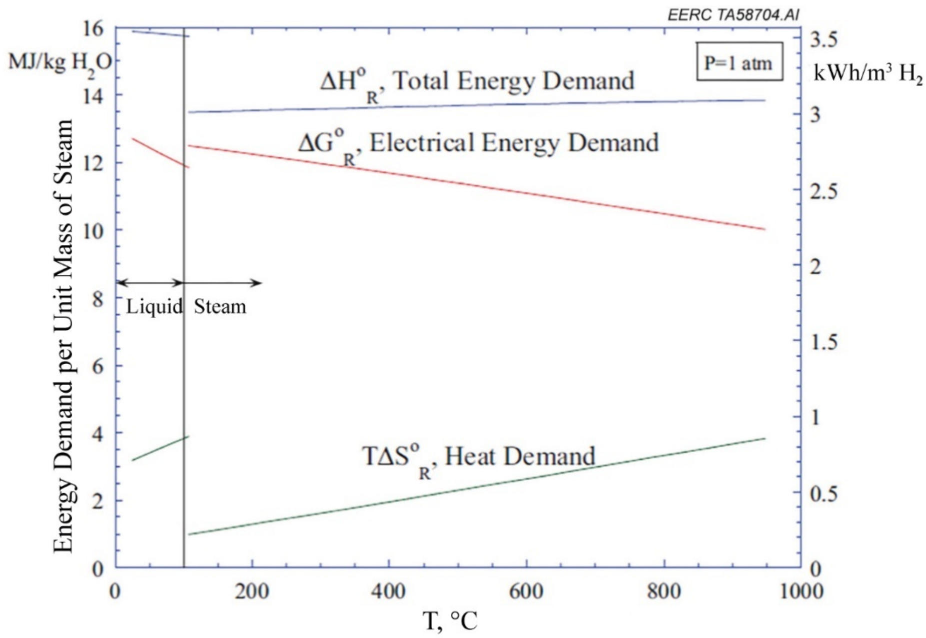

Figure 3. Standard state ideal energy requirements for electrolysis as a function of temperature.[1]

2) using the model to simulate and optimize NH_3-BEST integration with a commercially operating EGU (currently identified integration optimization parameters are illustrated in Figure 4), and 3) using model outputs—along with utility partner-provided data and information—to demonstrate ease of EGU–NH_3-BEST integration and quantify EGU cost and performance benefits. In addition, to further support NH_3-BEST commercial viability, the project will include lab-scale demonstration of the 1-SEA process—ammonia production using inputs of electricity, water, and air.

[1] O'Brien, J.E.; Stoots, C.M., et al. *High Temperature Electrolysis for Hydrogen Production from Nuclear Energy – Technology Summary*; Idaho National Lab Report INL/EXT-09-16140, 2010.

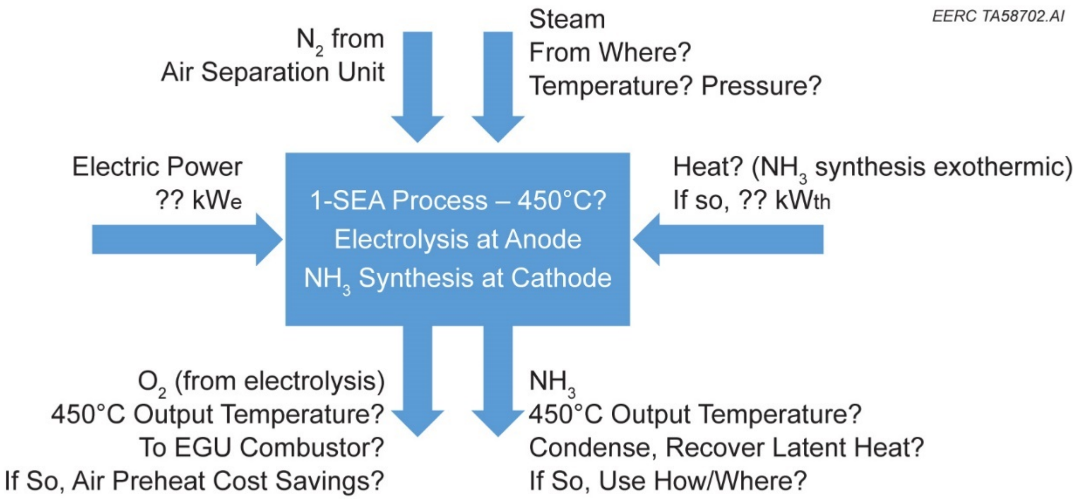

Figure 4. Parameters to evaluate to establish optimal EGU–NH_3-BEST integration scenario.

Background – Scientific/Engineering Basis of NH_3-BEST Concept

As an H_2 carrier, liquid NH_3 (~250 psi) contains more H_2 by volume than compressed gaseous or liquid H_2. NH_3 energy storage is fundamentally similar to H_2 energy storage (HES). Both involve the three stages of 1) gas production via electrolysis, 2) gas storage, and 3) gas conversion to electricity. The primary drawback of HES systems is low round-trip efficiency, approximately 30%,[2] due to losses through each stage. Electrolysis via a conventional proton exchange membrane (PEM) electrolyzer operating at 70°C is about 60% efficient. Although hydrogen compression to low storage pressures can be up to 90% efficient, low storage pressure translates to a large storage volume/footprint and high capital cost. PEM fuel cell conversion of hydrogen to electricity is approximately 50% efficient.

While NH_3 energy storage systems encompass the same three stages, important differences between NH_3 and H_2 offer opportunities for efficiency improvement. By utilizing available EGU steam/heat to operate the electrolysis–ammonia synthesis (1-SEA) unit at 300°–450°C as targeted, up to 20% of anode-side electrolysis energy can be provided by thermal rather than electrical energy, translating to 20% less electricity, cost, and CO_2 emissions versus standard PEM electrolysis. Because cathode-side ammonia

[2] Aneke, M.; Wang, M. Energy Storage Technologies and Real Life Applications – A State of the Art Review. *Applied Energy* **2016**, *179*, 350–377.

synthesis is exothermic, the resulting heat can be strategically deployed/integrated for efficiency gain. NH_3 compression for storage (as liquid) at 250 psi means low-capital-cost, small-footprint storage, and low energy consumption/cost compression (versus hydrogen), translating to increased round-trip efficiency. As a mature technology, affordable and efficient NH_3 storage systems are widely commercially available, while H_2 storage systems are often designed to be application-specific, elevating system costs. While not commercially available today, DAFC technologies are undergoing development around the world in response to 1) widely increasing recognition of ammonia as a carbon-free fuel (meaning no CO_2 emissions from either combustion or electrochemical conversion) and 2) the fact that when ammonia is produced using electricity generated at a power plant equipped with CO_2 capture capability, ammonia offers the possibility of a "near-zero" life cycle carbon emission fuel.[3]

Background – Scientific/Engineering Basis of Electrolytic Ammonia Production Via 1-SEA Process

Because of high molecular nitrogen (N_2) stability, conventional Haber–Bosch processes rely on high temperature and pressure (about 400°C and 3000 psi) to drive ammonia synthesis. High temperature and pressure act to increase the occurrence probability of catalyst surface hydrogen–nitrogen molecular interactions needed to achieve commercially relevant ammonia synthesis rates. With the use of electricity as a reaction driver, the 1-SEA process enables control of catalyst–surface hydrogen–nitrogen activity, eliminating the need for high pressure. The EERC low-pressure electrolytic ammonia process (precursor to 1-SEA) uses an EERC-developed ≥300°C-capable proton exchange electrolyte built around cerium ultraphosphate as a proton-conducting medium. Because the low-pressure electrolytic ammonia process uses hydrogen as anode input, an important project objective is validating ammonia synthesis via the 1-SEA process, which uses water, rather than hydrogen, as anode input.

Background – Scientific/Engineering Basis of NH_3 Storage

High-efficiency, affordable, safe, industrial-scale ammonia storage systems are commercially available.

[3] Brown, T. Green Ammonia at Oil and Gas Scale: The 15 GW Asian Renewable Energy Hub. Ammonia Energy News, 6 August 2020, ammoniaenergy.org (accessed 2021).

Background – Scientific/Engineering Basis of DAFC

DAFC development work has achieved power densities of about 0.6 and 0.7 watts/cm^2 with high-temperature solid oxide (O^{2-} ion exchange) and proton exchange electrolyte systems, respectively,[4] versus about 1.3 watts/cm^2 for today's commercially available PEM fuel cells. Because of increasing worldwide recognition of ammonia's attributes as a fuel for fuel cells, major ongoing DAFC technology development efforts will likely lead to commercially competitive power densities.

Project Work Scope: The work scope will define and build (using Aspen process simulation software) a basic model of the NH_3-BEST concept/subsystem comprising 1) electrolytic ammonia production, 2) ammonia storage, and 3) ammonia conversion to electricity via DAFC. The basic model will be tailored for application to the energy storage scenarios developed for each utility and used to assess NH_3-BEST impacts on utility performance and economics. Additional work includes demonstration of ammonia synthesis from electricity, water, and air-separated nitrogen (the 1-SEA process) and networking to advance NH_3-BEST toward commercial deployment. Proposed tasks are described below.

Task 1 – Project Management – M1–M12

Task 1 encompasses all activities related to project direction, communication with all technical and nontechnical participants, and meeting all reporting and deliverable requirements.

Task 2 – Define NH_3-BEST – M1–M6

Utility-provided EGU load cycling and other relevant data and information will be utilized to define 1) NH_3-BEST operational (power output) range, 2) minimum energy storage requirement (in MW), and 3) energy storage duration range. The EERC team will then define the operating parameters and performance metrics for NH_3-BEST to fulfill the energy storage needs.

Task 3 – Build Basic Model of NH_3-BEST – M1–M6

NH_3-BEST comprises the optimally integrated unit operations of electrolytic ammonia production, ammonia storage, and ammonia conversion to electricity via DAFC. The resultant behavior of this

[4] Ishak, F.; Dincer, I.; Zamfirescu, C. Thermodynamic Analysis of Ammonia-Fed Solid Oxide Fuel Cells. *Journal of Power Sources* **2012**, *202*, 157–165.

integrated system is difficult to predict through traditional analysis alone; as a result, a basic NH_3-BEST model will be designed to provide insight into critical performance attributes and establish initial performance requirements of the integrated three-component system. Aspen HYSYS, an industrial process modeling and simulation package, will be used to create a basic NH_3-BEST model based on process boundary conditions, in addition to the parameters identified in Task 2.

Task 4 – Evaluate NH_3-BEST Performance and Economics – M4–M12

The basic NH_3-BEST model will be tailored as needed for application to each utility's energy storage scenario and used to assess and optimize performance and economic impacts.

Task 5 – Complete R&D for 1-SEA Process Proof-of-Concept Validation – M4–M12

State-of-the-art materials and techniques deployed in fabrication of PEM electrolyzer and fuel cell membrane–electrode assemblies (MEAs)—including catalyst ink formulations, electrode microstructures, and MEA configurations—will be leveraged and tailored as required for application to MEA fabrication for the 1-SEA system. The two primary strategies for MEA fabrication—catalyst-coated membrane (CCM) and catalyst-coated substrate (CCS)—will be explored, and an optimal method will be identified based on compatibility with the cathode (nitrogen reduction reaction) catalyst. Fabricated MEAs will be assembled into a working 50-cm^2 1-SEA unit-cell system and undergo in situ electrochemical diagnostics. MEA evaluation will be conducted using electrochemical techniques such as current–voltage (I–V) polarization curves, cyclic voltammetry (CV), and electrochemical impedance spectroscopy (EIS). The electrochemical in situ evaluation will be conducted to generate data for benchmarking and to gain a deeper understanding of the fundamental mechanisms related to MEA performance in a 1-SEA system.

Task 6 – Network with Industrial Technology Developers and End Users – M1–M12

Progress and findings will be communicated with project utility partners and other potential end users (as approved by utility partners) with the goal of building a team and securing funding for NH_3-BEST pilot-scale demonstration at a working power plant. Industry outreach will be guided by project team member Dr. Chock Karuppaiah of Vetri Labs. Prior to starting Vetri Labs, Chock spent 18 years helping fuel cell industry leaders Plug Power and Bloom Energy design and commercialize new fuel cell technologies.

Chock's design innovations contributed to sales and installation of 500 MW of fuel cell capacity throughout the United States.

Anticipated Results: Anticipated results include the following:

- Preliminary design of NH_3-BEST subsystem.
- Defined set of requirements for power plant–NH_3-BEST integration.
- Establishment of NH_3-BEST performance and cost targets to meet utility requirements for deployment.
- Identification of necessary work to advance to component-level engineering and validation testing (to be documented in a separate "technology maturation plan/commercialization strategy" deliverable).
- Identification of technical and nontechnical gaps to resolve for NH_3-BEST commercial deployment.
- Demonstration of the 1-SEA process (ammonia synthesis from electricity, water, and air-separated nitrogen).

Facilities, Resources, and Techniques: The EERC and Vetri have the personnel, facilities, and resources needed for successful project performance, including a highly experienced and creative team of Aspen process simulation software-capable modelers and electrochemists. Aspen-based modeling at the EERC will be performed on existing workstations. The EERC's fully integrated low-, medium-, and high-temperature fuel cell and electrolyzer test system will be utilized to complete R&D for proof-of-concept validation of the 1-SEA process (ammonia production from electricity, water, and nitrogen) using an electrochemical unit cell configuration. Personnel availabilities are adequate. Project partners Minnkota Power Cooperative, Basin Electric Power Cooperative, and Otter Tail Power Company have committed to providing the operational data, performance targets, and support needed for development and deployment of reliable models for accurately assessing NH_3-BEST effectiveness and economics as a load-management asset.

Environmental and Economic Impacts of Underway Project: The project comprises communication, process modeling, and lab-scale electrochemical research. Environmental and economic impacts of project will be minimal.

Ultimate Techno-Economic Impacts: Figure 5 shows the cost benefit of NH_3 as an easily storable energy carrier versus other energy storage options.[5] Other benefits include 1) high reliability resulting from the solid-state structure of ammonia synthesis and conversion (to electricity) unit operations; 2) the availability of oxygen (generated as coproduct of water electrolysis and nitrogen separation from air) for monetization via options to be explored in the project; and 3) the existing ammonia industry, which offers the potential—if needed and/or economically advantageous for the utility operator—for selling ammonia into the fertilizer market or buying ammonia for supply replenishment.

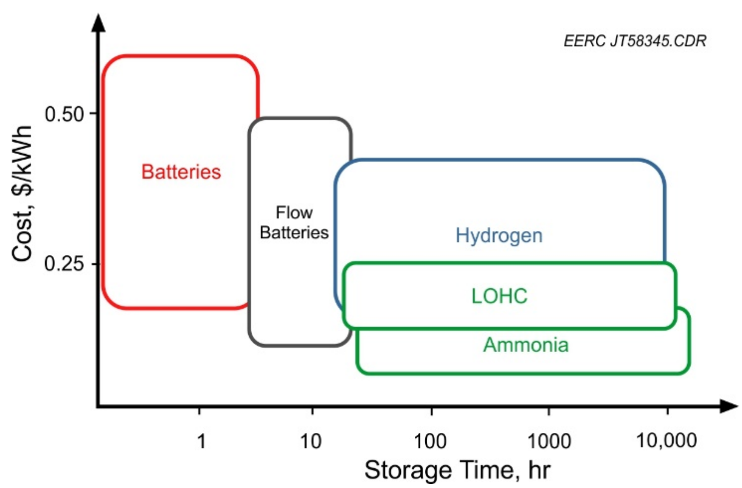

Figure 5. Levelized cost of energy storage options (LOHC = liquid organic hydrogen carrier).

Why Project Is Needed: The high relevance of the proposed project to the lignite industry derives from ammonia's unique set of chemical, physical, and economic attributes as an energy storage medium for North Dakota power plants and nitrogen source for North Dakota (and beyond) agriculture. In addition to

[5] Soloveichik, G. Ammonia for Energy Storage and Delivery. Presented at NH_3 Fuel Conference, Sept 19, 2016, ammoniaenergy.org (accessed 2021).

its carbon-free composition, high hydrogen content, low storage cost, and near-zero explosivity hazard, ammonia is a long-established, globally fungible commodity. The highly developed ammonia industry represents an NH_3-BEST economic flexibility attribute, since it opens possibilities for selling and/or buying ammonia to capitalize on market conditions or address production or supply challenges. Major project outcomes will be:

- Preliminary design of NH_3-BEST subsystem and associated lignite EGU integration requirements.
- Modeled demonstration of NH_3-BEST performance, including estimated round-trip efficiency and preliminary economics when integrated with a lignite EGU.
- A road map for bringing ammonia energy storage to commercial deployment, including identification of work needed to advance to component-level engineering and validation testing, and technical and nontechnical challenges to resolve.

STANDARDS OF SUCCESS

The project target is a model-demonstrated NH_3-BEST round-trip efficiency of at least 35% (versus hydrogen energy storage efficiency of 30%). It is envisioned that this target can be met through an optimal combination of high-temperature electrolysis, effective EGU–NH_3-BEST thermal energy integration, and adequate DAFC power density. Primary standards of success are:

- Development of a model that enables reliable assessment of integrated EGU–NH_3-BEST techno-economic performance, as indicated by utility partner confidence in the validity of model outputs.
- Model-demonstrated NH_3-BEST round-trip efficiency of ≥35%.
- Demonstration of 1-SEA process—ammonia synthesis from inputs of electricity, water, and nitrogen.
- Based on project outcomes, interest by at least one utility partner in exploring options for integrating pilot-scale ammonia production and/or utilization technologies at a North Dakota lignite power plant to 1) validate model-generated NH_3-BEST techno-economic performance data and 2) optimize and evaluate NH_3-BEST operational scenarios.

BACKGROUND/QUALIFICATIONS

With recognition of in-state electrolytic ammonia production as a means of adding value to North Dakota lignite-generated electricity, EERC initiated development of the low-pressure electrolytic ammonia (LPEA) process in 2008. With recognition of ammonia as the energy currency of the future, EERC proposed (to ARPA-E) development of a reversible ammonia fuel cell in 2009 (ARPA-E Concept Paper 25A2597, 2009). Currently ongoing work funded by the U.S. Department of Energy (DOE) Advanced Manufacturing Office, North Dakota State University (key technical collaborator with EERC), Nel Hydrogen (world leader in electrochemical hydrogen production), and the North Dakota Industrial Commission (NDIC) has advanced the LPEA process to DOE-designated Technology Readiness Level 4 (TRL4), with TRL5 targeted at project completion in December 2021. TRL5 signifies technology validation at lab scale, TRL7 signifies validation at pilot scale, and TRL9 signifies readiness for commercial deployment. Task 5 work proposed here will attempt to incorporate electrolysis into the LPEA process and demonstrate 1-step electrolytic ammonia production—the 1-SEA process.

Principal Investigator (PI) Ted Aulich has over 25 years of energy technology development experience including developing (with EERC team member Dr. Jivan Thakare) an innovative high-temperature, high-proton-conductivity (0.01 siemens/centimeter at 300°C) proton exchange electrolyte, critical enabling technology for the low-pressure electrolytic ammonia process on which 1-SEA is based. Mr. Aulich is currently leading—in collaboration with Dr. Thakare—the $3.2-million, 3-year, multipartner DOE Advanced Manufacturing Office-funded Low-Pressure Electrolytic Ammonia Production Project. Dr. Jivan Thakare[6] played a major role in EERC work with the National Energy Technology Laboratory (NETL) to define power plant model Cases 11 and 12 (state-of-the-art 550-MW supercritical pulverized coal-fired power plant both with and without CO_2 capture).[7] Team member Dr.

---

[6] Stanislowski, J.J.; Folkedahl, B.C.; Jensen, M.D.; Schlasner, S.M.; Wocken, C.A.; Patel, N.M.; Thakare, J.; Musich, M.A. *Subtask 2.3 – Support of DOE Carbon Capture Systems Development and Modeling*; Final Report (July 16, 2016 – Feb 28, 2019) for DOE NETL Cooperative Agreement No. DE-FE0024233; EERC Publication 2019-EERC-03-01; Mar 2019.

[7] Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity; Revision 2. DOE/NETL, 2010/1397.

Daisy Selvaraj has over 5 years of experience in grid integration of fossil and renewable energy resources, distribution system planning, condition assessment of high-voltage apparatus, and use of machine learning algorithms/big data analytics for cyber physical system improvement.

In his career, with positions at Plug Power, Case Western Reserve University, and Bloom Energy and his current position as founder and CEO of Vetri Labs, Dr. Chock Karuppaiah has played key technical and management roles in delivery of two generations of polymer electrolyte fuel cell stacks and four generations of solid oxide fuel cell systems. Dr. Chock and his team were responsible for the design and deployment of technology innovations that led to sales and installation of 500 MW of fuel cell capacity throughout the United States.

Utility partners Minnkota, Basin Electric, and Otter Tail Power Company operate coal-fired baseload power plants ranging in capacity from 400 to 1700 MW in North and South Dakota, Wyoming, Montana, and Iowa. EERC has a 30+-year history of working with utilities and commercial technology vendors to develop and optimize fossil power plant operations, including development and use of models for simulation of CO_2 capture and NO_x, mercury, and other emission reduction technologies.

VALUE TO NORTH DAKOTA

Because three North Dakota utilities will help develop a foundational NH_3-BEST model, define plant-specific operational scenarios for evaluation via the model, and provide model inputs for each scenario, project results will have high relevance to the North Dakota lignite-based power industry. A means of profitably integrating lignite power and ammonia production would enable building and operating new industrial-scale technologies, translating to good jobs and expanding the scope and value of North Dakota energy and agricultural economies.

MANAGEMENT

The project organization structure is illustrated in Figure 6. Work efforts will be coordinated via regular and as-needed communication between EERC, Vetri, Minnkota Power, Basin Electric, and Otter Tail Power. Participant roles are summarized below:

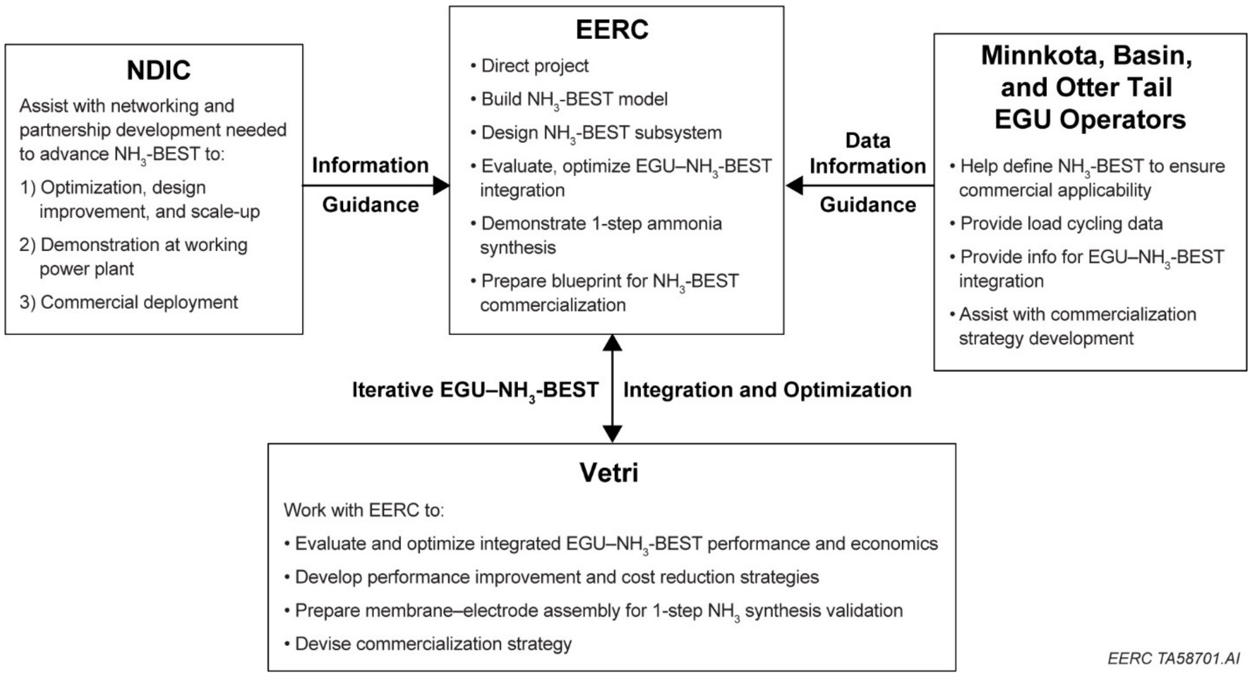

Figure 6. Project organization structure.

- EERC – define NH_3-BEST with commercially relevant inputs from Minnkota, Basin, and Otter Tail; utilize data as basis for building basic NH_3-BEST models; conduct preliminary conceptual study of integrated EGU + NH_3-BEST. Complete R&D for 1-step NH_3 synthesis, and prepare blueprint for NH_3-BEST commercialization.
- Vetri – assist EERC in all aspects of project, including providing guidance on MEA fabrication for 1-step NH_3 synthesis and development and assessment of NH_3-BEST performance improvement and cost reduction strategies.
- Minnkota Power, Basin Electric, Otter Tail Power – provide data and guidance for NH_3-BEST definition, subsystem design, integration with EGU operations, and advancement toward power plant demonstration and commercialization.

TIMETABLE AND DELIVERABLES

Ammonia-Based Energy Storage Technology (NH_3-BEST)	April 1, 2021 – March 31, 2022			
	Q1	Q2	Q3	Q4
Task 1 – Project Management		D1	D1	D1
Task 2 – Define NH_3-BEST				
Task 3 – Build a Basic Model of NH_3-BEST		M1		
Task 4 – Evaluate NH_3-BEST Performance and Economics			M2	EPG
Task 5 – Complete R&D for 1-SEA Process Proof-of-Concept Validation				
Task 6 – Network with Industrial Technology Developers and End Users				

Milestone (M)

M1 – Complete Basic Model of NH_3-BEST

M2 – Identify EGU (power plant) integration requirements for NH_3-BEST

End-of-Project Goal (EPG)

EPG – Demonstrate EGU + NH_3-BEST round-trip efficiency of 35%. Demonstrate 1-SEA process in lab.

Deliverables (D)

D1 – Quarterly Project Report

D2 – Technology Maturation Plan (TMP) – due within 90 days of project completion

D3 – Basic Model and Preliminary Conceptual Study – due within 90 days of project completion

BUDGET

Project Associated Expense	NDIC Share (Cash)	DOE Share (Cash)	Commercial Share (In-Kind)	Total Project
Labor	$ 61,284	$ 115,857	$ -	$ 177,141
Supplies	$ 49	$ 2,551	$ -	$ 2,600
Subcontractor - Vetri Labs	$ -	$ 50,400	$ -	$ 50,400
Communications	$ -	$ 175	$ -	$ 175
Printing & Duplicating	$ -	$ 215	$ -	$ 215
Laboratory Fees & Services				
Technical Software Fee	$ 4,944	$ 3,708	$ -	$ 8,652
Engineering Services Fee	$ 869	$ 1,236	$ -	$ 2,105
Total Other Direct Costs	$ 5,862	$ 58,285	$ -	$ 64,147
Total Direct Costs	$ 67,146	$ 174,142	$ -	$ 241,288
Facilities & Administration	$ 34,244	$ 75,858	$ -	$ 110,102
Total Cash Requested	**$ 101,390**	**$ 250,000**	**$ -**	**$ 351,390**
In-Kind Cost Share				
Basin Electric	$ -	$ -	$ 25,000	$ 25,000
Minnkota Power	$ -	$ -	$ 25,000	$ 25,000
OtterTail Power	$ -	$ -	$ 25,000	$ 25,000
Total In-kind Cost Share	**$ -**	**$ -**	**$ 75,000**	**$ 75,000**
Total Project Costs	**$ 101,390**	**$ 250,000**	**$ 75,000**	**$ 426,390**

Budget notes can be found in Appendix C. If less LRP funding is available, adjustments to scope will need to be considered.

MATCHING FUNDS

In response to an August 2020 EERC proposal, DOE's NETL recently awarded $250,000 to EERC for conducting the proposed project. Commitments to provide in-kind project services valued at $25,000 were received from each of three utility partners—Minnkota, Basin, and Otter Tail.

TAX LIABILITY

EERC, a department within UND, is a state-controlled institution of higher education and is not a taxable entity; therefore, it has no tax liability to the state of North Dakota or any of its political subdivisions.

CONFIDENTIAL INFORMATION

This proposal has no confidential information.

APPENDIX A

LETTERS OF SUPPORT

Minnkota Power COOPERATIVE
A Touchstone Energy® Cooperative

5301 32nd Avenue South
Grand Forks, ND 58201

Phone 701.795.4000
www.minnkota.com

August 9, 2020

Dr. Jivan Thakare
Senior Engineer, Electrochemical Process Development
Energy & Environmental Research Center
15 N 23rd Street
Grand Forks, ND 50203

RE: Support of the proposal EERC is submitting in response to DE-FOA-0002332 "Energy Storage for Fossil Power Generation"

Dear Dr. Thakare:

Minnkota Power Cooperative, Inc. (Minnkota) is pleased to express our support for the subject project for which a proposal is being submitted to the U.S. Department of Energy (DOE). The EERC is developing a novel process that uses electricity to convert water and nitrogen to ammonia for the purpose of energy storage. The DOE's interest in energy storage technologies for fossil generation aligns well with the interests of Minnkota Power Cooperative (MPC).

Minnkota is a not-for-profit electric generation and transmission cooperative headquartered in Grand Forks, ND. Formed in 1940, Minnkota provides wholesale electric energy to 11 member-owner distribution cooperatives located in eastern ND and northwestern MN under contractual obligations that currently extend through 2055. In addition, Minnkota serves as the operating agent for the Northern Municipal Power Agency ("NMPA"), a municipal joint action agency that serves as an energy supplier for 12 municipal utilities located within the Minnkota service area. In total, the Minnkota/NMPA "Joint System" provides electricity to more than 143,000 residential and commercial member consumers spanning over 34,500 square miles. The primary source of electric generation for the Minnkota member-owners is the Milton R. Young Station (MRYS), a two-unit, lignite coal-fired power plant located near the town of Center, ND.

Considering the nature and length of our obligation to meet the needs of our member owners, Minnkota is keenly interested in continuing to assess and develop new technologies and solutions to support the lignite industry. The development and deployment of cost-effective technologies to address intermittent operations and system cycling is critical need for existing lignite-fired power plants. Energy storage technologies have the potential significantly benefit MPC by reducing the need to ramp plants down to reduced loads during times of low power demand. Additionally, the technology proposed by the EERC has the potential to produce a high value commodity that is needed in North Dakota. As such, we will contribute operational data to the project to help EERC determine the benefit of the technology to our generation systems. Additionally, MPC will provide up to $25,000 of in-kind contribution to the project in the form of labor needed to gather and analyze the data, participation in meetings, and review of EERC deliverables.

We look forward to working with the EERC team on this project and hope that DOE gives careful consideration to this project. If you have any questions or require additional information, please contact me at 701-794-7234 or at gpfau@minnkota.com.

Sincerely,

Gerry Pfau
Sr. Manager of Project Development

Cc: Craig Bleth
Lowell Stave
Dylan Wolf
Joshua Stanislowski (EERC)

BASIN ELECTRIC
POWER COOPERATIVE
A Touchstone Energy® Cooperative

August 6, 2020

Dr. Jivan Thakare
Senior Engineer, Electrochemical Process Development
Energy & Environmental Research Center
15 N 23rd Street
Grand Forks, ND 50203

Dear Mr. Thakare:

Subject: EERC Proposal in Response to DE-FOA-0002332

This letter is in response to the Energy & Environmental Research Center's (EERC) request for participation in the subject proposed project for which a proposal is being submitted to the U.S. Department of Energy (DOE). The EERC is developing a novel process that uses electricity to convert water and nitrogen to ammonia for the purpose of energy storage. The DOE's interest in energy storage technologies for fossil generation aligns well with the interests of Basin Electric Power Cooperative (Basin Electric).

Basin Electric is committed to providing wholesale power to member rural electric systems in nine states. The development and deployment of cost-effective technologies to address intermittent operations and system cycling is needed for existing power plants. Energy storage technologies have the potential to significantly benefit Basin Electric by reducing the need to ramp plants down to reduced loads during times of low power demand. Additionally, the technology proposed by the EERC has the potential to produce a high value commodity that is utilized in Basin Electric's service area. As such, we will contribute operational data to the project to help EERC determine the benefit of the technology to our generation systems. Additionally, BEPC will provide up to $25,000 of in-kind contribution to the project in the form of labor needed to; 1) gather and analyze the data, 2) participate in meetings, and 3) review EERC deliverables.

We hope that the DOE gives careful consideration to this project, as there is a significant need for projects that promote the continued responsible use of coal. Again, we express our interest in and support of the proposed project and look forward to working with the project team on this effort.

Sincerely,

Gavin McCollam
Gavin McCollam (Aug 6, 2020 10:44 CDT)

Gavin McCollam
VP Engineering & Construction
Basin Electric Power Cooperative

215 South Cascade Street
PO Box 496
Fergus Falls, Minnesota 56538-0496
218 739-8200
www.otpco.com

March 30, 2021

Dr. Jivan Thakare
Senior Engineer, Electrochemical Process Development
Energy & Environmental Research Center
15 N 23rd Street
Grand Forks, ND 50203

Dear Mr. Thakare:

Subject: EERC Proposal: 2021-0106: Ammonia-Based Energy Storage Technology (NH3-BEST)

This letter is in response to the Energy & Environmental Research Center's (EERC) request for participation in the subject proposed project for which a proposal is being submitted to the North Dakota Industrial Commission (NDIC) through the Lignite Research Council (LRC). A proposal has previously been submitted to the US Department of Energy (DOE) and was awarded to EERC. The EERC is developing a novel process that uses electricity to convert water and nitrogen to ammonia for the purpose of energy storage.

Otter Tail Power Company (OTP) is an investor-owned electric utility that is committed to providing electricity for residential, commercial, and industrial customers in Minnesota, North Dakota, and South Dakota. The development and deployment of cost-effective technologies to address intermittent operations and system cycling is needed for existing power plants. Energy storage technologies have the potential to significantly benefit OTP by reducing the need to ramp plants down to reduced loads during times of low power demand. Additionally, the technology proposed by the EERC has the potential to produce a high value commodity that is utilized in OTP's service area. As such, we will contribute operational data to the project to help EERC determine the benefit of the technology to our generation systems.

Additionally, OTP will provide up to $25,000 of in-kind contribution to the project in the form of labor needed to: 1) gather and analyze the data, 2) participate in meetings, and 3) review EERC deliverables.

We hope that the NDIC and LRC give careful consideration to this project, as there is a significant need for projects that promote the continued responsible use of coal. Again, we express our interest in and support of the proposed project and look forward to working with the project team on this effort.

Sincerely,

Mark Thoma
Manager, Environmental Services

C: Brad Zimmerman, Manager Coyote Station

APPENDIX B

RESUMES OF KEY PERSONNEL

TED R. AULICH
Principal Process Chemist, Fuels and Chemicals
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.2982 (phone), 701.777.5181 (fax), taulich@undeerc.org

Qualifications
B.S., Chemistry, University of North Dakota, Grand Forks, North Dakota, 1986.
B.S., Biology, University of St. Thomas, St. Paul, Minnesota, 1982.

Professional Experience
1989–Present: Principal Process Chemist, Fuels and Chemicals, EERC, UND.

- Directs renewable/alternative energy, fuel, and chemical technology development projects worth $50K–$5M, responsible for meeting performance, schedule, and cost targets.
- Prioritizes/plans/directs activities of multidisciplinary staff in executing multiple projects in varying technology segments and at various stages of development.
- Leads EERE–AMO-funded project to develop low-pressure electrolytic ammonia (LPEA) production technology built around 300°C-capable proton exchange membrane (PEM).
- Codeveloped patented low-pressure processes for electrochemical production of ammonia from water and nitrogen, syngas and nitrogen, or hydrogen and nitrogen.
- Developed patented process and reactor design for on-demand production of high-pressure, PEM fuel cell (PEMFC)-quality hydrogen from methanol.
- Developed NO_x emission control technology pathway in which NO_x is recovered and input to electrolytic ammonia production process powered by renewable and/or off-peak electricity.
- Codeveloped unique silica-based composite electrocatalyst support with high potential for eliminating PEMFC catalyst layer corrosion, improving catalyst durability and performance.
- Developed/directed $5M, multipartner DARPA-funded project that yielded patented and commercially competitive processes for producing U.S. military specification-compliant jet and diesel fuels from renewable oil and other petroleum-alternative feedstocks.
- Developed/secured funding for $1M project to deliver front-end engineering design package for 3-mgy renewable oil refinery for jet/diesel fuel production.
- Partnered with U.S. Air Force in using a test stand-mounted jet aircraft engine to assess performance and emission effects of blending biodiesel into military jet fuel.

1987–1989: Technical Editor, EERC, UND**.**

1985–1987: Analytical Chemist, EERC, UND.

1983–1985: Quality Control Manager, H.B. Fuller Industrial Coatings, St. Paul, Minnesota.

Relevant Publications

Zholobko, O.; Wu, X.-F.; Zhou, Z.; Aulich, T.; Thakare, J.; Hurley, J. A Comparative Experimental Study of the Hygroscopic and Mechanical Behaviors of Electrospun Nanofiber Membranes and Solution-Cast Films of Polybenzimidazole. *J. Appl. Poly. Sci.*, in press.

Jiang, J.; Aulich, T.R.; Ignatchenko, A.V. Electrochemical Process for the Preparation of Nitrogen Fertilizers. U.S. Patent 9,005,422 B2, April 14, 2015.

Collings, M.E.; Aulich, T.R.; Timpe, R.C.; Holmes, M.J. System and Process for Producing High-Pressure Hydrogen. U.S. Patent 8,182,787 B2, May 22, 2012.

Jiang, J.; Aulich, T.R. High Activity and Durability of Pt Catalyst Toward Methanol Electrooxidation in Intermediate Temperature Alkaline Media. *J. Power Sources* **2012,** *209*, 189–194.

Oster, B.G.; Timpe, R.C.; Aulich, T.R.; Lin, M.C.J.; Holcomb, F.H. On-Demand Hydrogen via High-Pressure Water Reforming for Military Fuel Cell Applications. *J. Fuel Cell Sci. Technol.* **2008,** *5* (4).

Olson, E.S.; Sharma, R.K.; Aulich, T.R. Higher-Alcohols Biorefinery: Improvement of the Catalyst for Ethanol Conversion. *Appl. Biochem. Biotechnol*. **2004**, *113–116*, 913–932.

Synergistic Activities

Designed and conducted economic and regulatory compliance evaluation of steam generation options for 60-mgy ethanol plant.

Prepared economic analysis to estimate costs of meeting air quality objectives likely to follow EPA designation of major city as ozone nonattainment area.

Formulated high-performance ethanol-based aviation fuel certified by the U.S. Federal Aviation Administration as alternative to lead-containing aviation gasoline.

Designed/directed industry–government-cost-shared study to assess technical/economic feasibility of on-site production of high-pressure hydrogen for fuel cell vehicles.

DR. JIVAN THAKARE
Senior Research Engineer, Electrochemical Process Development
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5567 (phone), 701.777.5181 (fax), jthakare@undeerc.org

Principal Areas of Expertise

Dr. Thakare has a strong background in natural gas engineering and process simulation, and his principal areas of interest and expertise include oil and gas production optimization, process modeling, emission control and environmental remediation, materials for renewable energy/fuels and energy devices, and data reduction.

Qualifications

Ph.D., Chemical Engineering, University of North Dakota, 2016. Dissertation: "Effects of Pt/Si Nanocatalyst on the Performance and Durability of PEM Fuel Cell."
M.S., Chemical Engineering, Texas A&M University, 2009. Project: "A Correlation for Predicting Flooding Velocities and Souder-Brown K-Value for Knitted Wire Mesh Packing."
B.S., Polymer Technology, College of Engineering and Technology Akola (COETA), India, 2000. Thesis: "A Study on Polyolefin Waste for Eco-Friendly Application (Energy Recovery)."

Professional Experience

Oct 2013–Present: Senior Research Engineer, EERC, UND.

- Leads Electrochemical Process Development Team to research, develop, and demonstrate electrochemical technologies for bidirectional conversion of electrical and chemical energy.
- Major federal and state research funding acquired includes the following:
  - **PI**, North Dakota State Energy Research Center (SERC), $25,000, Electrochemical Extraction of REEs from North Dakota Lignite, 07–11/20.
  - **PI**, Postdoctoral Seed Funding Program, UND, $70,000, Enhanced Performance of All-Inorganic $CsPbBr_3$ Perovskite Solar Cells by Using Plasmonic Nanoparticles, 07/20–06/21.
  - **PI**, SERC, $150,000, Electrochemical Ethanol Production Enhancement, 01–09/20.
  - **PI**, Postdoctoral Seed Funding Program, UND, $70,000, High-Durability Novel Composite Support for PEM Fuel Cell Electrocatalyst, 07/19–06/20.
  - **Co-PI**, U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL), $4,000,000, Solid Oxide Fuel Cell Development and Demonstration Test Center, 05/19–05/21.
  - **Co-PI**, DOE Energy Efficiency and Renewable Energy, $3,160,000, Proton Exchange-Based Electrochemical Process Capable of Low-Pressure Production of Ammonia, 06/18–06/21.
  - **Co-PI**, FuelCell Energy/Advanced Research Programs Agency-Energy (ARPA-E), $300,000, Electrochemical Methane-to-Methanol Technology Development, 05/15–05/16.
- Major Pending Proposals:
  - **Co-PI,** DOE, $4,000,000, Coal Syngas Cleanup for Commercially Viable SOFC Performance (expected decision – 10/20).

2009–2013: Graduate Research Assistant, UND. Synthesized and characterized silica-supported platinum nanocatalyst. Designed, built, and validated laboratory-scale fuel cell test station. Fabricated and evaluated catalyst-coated gas diffusion layer MEA.

2006–2007: Lecturer, Plastic Engineering, Government Polytechnic Institute, Nashik, India. Taught and advised plastic engineering diploma students; courses: Polymer Materials, Polymer Testing, Polymer Processing, Industrial Economics; labs: Polymer Testing and Polymer Processing. Managed polymer testing and polymer processing laboratories and staff.

2003–2006: Quality Control Engineer, Kalpana Plastics & Chemicals, Indore, India. Developed SOP for QC of in-process and packaging materials. Reviewed production record, investigated out-of-specifications/violations, and conducted corrective actions.

Relevant Publications/Patents

Zholobko, O.; Wu, X.-F.; Zhou, Z.; Aulich, T.; Thakare, J.; Hurley, J. A Comparative Experimental Study of the Hygroscopic and Mechanical Behaviors of Electrospun Nanofiber Membranes and Solution-Cast Films of Polybenzimidazole. *Journal of Applied Polymer Science*, in press.

Aulich, T.; Thakare, J.; Hurley, J.; Wu, X.; Zholobko, O. Ultraphosphate proton conductor-based proton exchange membrane. U.S. Provisional Patent Application, 2019.

Stanislowski, J.J.; Folkedahl, B.C.; Jensen, M.D.; Schlasner, S.M.; Wocken, C.A.; Patel, N.M.; Thakare, J.; Musich, M.A. *Subtask 2.3 – Support of DOE Carbon Capture Systems Development and Modeling*; Final Report for DOE NETL Cooperative Agreement DE-FE0024233; 2019-EERC-03-01; 2019.

Synergistic Activities

Leads the Electrochemical Process Development Team.

Has served as PI, Co-PI, and task lead on several major federal (DOE), state, and commercially funded research projects, as highlighted under Research and Professional Experience.

DR. CHOCKKALINGAM KARUPPAIAH
CEO
Vetri Labs
44240 Fremont Boulevard, Fremont, California 94538 USA

Principal Areas of Expertise

Dr. Chockkalingam has over 22 years of experience in electrochemical and energy product development. The products he developed include polymer electrolyte fuel cells, flow batteries and solid oxide fuel cells. He was part of the design, development, and manufacturing scaleup of seven different products. Dr. Chockkalingam's professional experience includes being Vice President of Engineering at Bloom Energy, founder at EC Labs, Research Professor at Case Western Reserve University, Manager of the Fundamentals Team at Plug Power, and Research Staff at Los Alamos National Laboratory. He has authored 19 published patents.

Qualifications

Ph.D., Chemistry, Rensselaer Polytechnic Institute, 1997.
B.Tech., Electrochemical Engineering, Central Electrochemical Research Institute, 1993.

Professional Experience

2019–Present: CEO, Vetri Labs, Fremont, California.
2018–2019: VP, Fuel Cell Stack Engineering, Bloom Energy, Sunnyvale, California.
2014–2018: Senior Director, Fuel Cell Stack Engineering, Bloom Energy.
2010–2014: Director, Fuel Cell Stack Engineering, Bloom Energy.
2007–2010: Consultant, EC Labs, Fremont, California.
2004–2007: Director, Quality Engineering, Bloom Energy.
2002–2004: Research Professor, Case Western Reserve University, Cleveland, Ohio.
1997–2002: Scientist and Manager, Plug Power.
1996–1997: Staff Research Assistant, Los Alamos National Laboratory.

Relevant Publications

Karuppaiah, C.; Wu, Y. Fuel Cell Having a Nonelectrolytic Layer. U.S. Patent 6,756,150, 2004.

Lakshmanan, B.; Karuppaiah, C. Carbon Monoxide Filter, U.S. Patent 6,517,963, 2003.

Gasda, M.; Ballantine, A.; Karuppaiah, C.; Winston Ho, W.S. Carbon Dioxide Separator, Fuel Cell System Including the Same, and Method of Operating the Same. U.S. Patent 10,186,724, 2019.

Haridoss, P.; Karuppaiah, C.; McElroy, J.F.; Boyer, J.R.; Budeshim, E.G. Hydrophilic Anode Gas Diffusion Layer. U.S. Patent 6,821,661, 2004.

Keshavarz, M.; Sahu, S.K.; Karuppaiah, C.; Zu, G.; Kumar, S.; Nair, S.; Mani, V. Methods of Producing Hydrochloric Acid from Hydrogen Gas and Chlorine Gas. U.S. Patent 8,551,299, 2013.

Hickey, D.; Karuppaiah, C.; McElroy, J.F. Reduction of SOFC Anodes to Extend Stack Lifetime. U.S. Patent 7,514,166, 2009.

Couse, S.; Darga, D.; Herchen, H.; Karuppaiah, C. Fuel Cell Interconnect. U.S. Patent 9,570,769, 2017.

Perry, M.; Ballantine, A.; Gasda, M.; Karuppaiah, C. SOFC System and Method Which Maintain a Reducing Anode Environment. U.S. Patent 10,361,442, 2019.

Wnek, G.E.; Sheikh-Ali, B.M.; Serpico, J.M.; Ehrenberg, S.G.; Tangredi, T.N.; Karuppaiah, C.; Ye, Y. Ion-Conducting and Electroactive Block Polymer Membranes. *Polymer Preprints* **1998**, *39* (1), 54–55.

Karuppaiah, C.; Rider, J.N.; Wnek, G.E. Applications of a Sulfonated Triblock Copolymer for Chemically Modified Electrode. *Polymer Preprints* **1996**, *211* (2), 411.

Synergistic Activities

Development of an electrochemical system to enable carbon dioxide separation.
Development of oxidatively stable conductive support material for fuel cell catalyst materials.
Catalytic improvement of electrochemical peroxide generation for onsite disinfectant production.
Techno-economic analysis of power backup solutions for CalTrans during public safety power shutdown.
Technical advising in development of PEM and anion exchange membrane based electrolyzer systems.

JOHN A. BRUNNER
Research Engineer
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
Phone: (701) 777-5059, Fax: (701) 777-5181, E-Mail: jbrunner@undeerc.org

Principal Areas of Expertise
Mr. Brunner's principal areas of interest and expertise include design and modeling of experimental equipment, gasification and combustion technologies, energy storage systems, and renewable energy technologies.

Qualifications
B.S., Mechanical Engineering, University of North Dakota, 2019.
Software experience includes Microsoft Office Suite, PTC Creo, Visio, Autodesk, MATLAB, GT Suite, and Solidworks.
Fabrication experience includes pipe/tube bending and cutting and MIG and SMAW welding.

Professional Experience
May 2019–Present: Research Engineer, EERC, UND. Contributes to design, modeling, and fabrication of experimental equipment, including overseeing and operating equipment; assists in preparation of proposals; interprets data; writes reports and papers; and presents results to clients and papers at national and international conferences. Principal areas of expertise include design and modeling of experimental equipment, gasification and combustion technologies, energy storage systems, and renewable energy technologies.

April 2018–April 2019: Research Engineering Assistant, EERC, UND.
- Worked on the design and modeling of flue gas exhaust.
- Assisted in modeling of a carbon dioxide capture system.
- Modeled a portable baghouse.
- Led a project to integrate virtual reality into the engineering design process.

February 2016–April 2018: Facilities and Safety Assistant, EERC, UND.
- Conducted scheduled safety inspections.
- Assisted in the hazard communication program.
- Calibrated and maintained safety equipment.

Summers 2015–2017: Laboratory Intern, RMB Environmental Laboratories, Detroit Lakes, Minnesota.
- Conducted nitrate and nitrite testing.
- Assisted in total phosphorus, ortho-phosphorus, biological oxygen demand, chemical biological oxygen demand, bacteria, and solids testing.

Relevant Publications

Brunner, J.A.; Anderson, J.D. *Evaluation of Energy Storage Technologies and the Benefit to North Dakota Utilities*; Final Report for State Energy Research Center; EERC Publication 2020-EERC-02-05; Energy & Environmental Research Center: Grand Forks, ND, Feb 2020.

Newman, T.K.; Anderson, J.D.; Brunner, J.A.; Tolbert, S.G.; Kay, J.P. *Power Production and Distribution Resilience to Electromagnetic Pulses*; Final Report for State Energy Research Center; EERC Publication 2019-EERC-11-09; Energy & Environmental Research Center: Grand Forks, ND, Nov 2019.

Synergistic Activities

Key personnel on State Energy Research Center project, "Hosting Capacity Analysis for Improved Planning and Operations of North Dakota Distribution Networks," focused on how many distributed energy resources (DERs), which includes energy storage, can be integrated into the electrical grid and how the dynamics of the electrical grid are affected by these units.

Member, Tau Beta Pi: Engineering Honor Society.

DR. JAHANGIR MASUD
Research Scientist
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5272 (phone), 701.777.5181 (fax), jmasud@undeerc.org

Principal Areas of Expertise

Dr. Masud's principal areas of interest and expertise include electrocatalysts and catalysis; energy storage and conversion, especially fuel cell; water splitting; supercapacitors; CO_2 to fuels; and batteries and sensors.

Qualifications

Ph.D., Electrochemistry, Tokyo Institute of Technology, Japan, 2011.
M.S., Organic Chemistry, Shahjalal University of Science & Technology, Bangladesh, 2003.
B.S. Chemistry, Shahjalal University of Science & Technology, Bangladesh, 2001.

Techniques, Software, and Instrumentation

Catalysts/thin films/semiconductor synthesized using a variety of techniques: electrodeposition, hydrothermal, solvothermal, chemical vapor deposition, reflux column, focused ion beam (FIB)
Surface modification using vacuum coating and etching
Surface characterization techniques: scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy-dispersive spectrometry (EDS), x-ray diffraction (XRD), x-ray photoelectron spectroscopy (XPS), and optical microscopy
Analytical techniques: Fourier transform infrared (FTIR), ultraviolet (UV)-visible, high-performance liquid chromatography (HPLC), gas chromatography–mass spectroscopy (GC–MS), nuclear magnetic resonance (NMR), inductively coupled plasma–mass spectrometry (ICP–MS), and thermogravimetric analysis (TGA)
Electrochemical techniques: cyclic voltammetry (CV), linear sweep voltammetry (LSV), square wave voltammetry (SWV), differential pulse voltammetry (DPV), electrochemical impedance spectroscopy (EIS), rotating ring-disk electrode (RRDE), chronoamperometry, chronopotentiometry, membrane–electrode assembly (MEA), fuel cell, and battery
Software: Zview, XPSPEAK41, MS Office, Origin, ImageJ, and Matlab

Professional Experience

August 2019–Present: Research Scientist, EERC, UND. Conducts research on platinum group metal-free electrocatalysts on carbon-free supports for proton exchange membrane fuel cell (PEMFC) applications, electrochemical NH_3 synthesis and direct ammonia fuel cell, electrochemical enhancement of ethanol fermentation, rare-earth element extraction from lignite coals, and electrochemical corrosion.

September 2014–July 2019: Research Associate, Chemistry, Missouri University of Science and Technology (Missouri S&T), Rolla MO. Worked on "Transition Metal-Based Catalyst for Energy Storage and Conversion" and "Nonenzymatic biosensors" projects. Main contributor to secure $300K+ in NSF grants and published more than 15 peer-reviewed journal articles.

December 2012–September 2014: Postdoctoral Fellow, Chemical and Petroleum Engineering, University of Kansas, Lawrence. Worked on "Highly Active and Stable Electrocatalyst for HOR/HER in H_2–Br_2 Fuel Cell Applications" project.

April 2011–December 2012: Postdoctoral Fellow, Clean Energy Research Center, University of Yamanashi, Japan. Worked on "Highly CO-Tolerant PtRu/CB Catalyst for Anode in PEM Fuel Cell" project. Synthesized Pt_2Ru_3/C (~3 nm) catalyst and evaluated under a controlled environment (presence of 100% CO and high temperature) for hydrogen oxidation. Performed degradation behavior of MEAs at low- and high-humidity conditions.

April 2008–March 2011: Graduate Student, Tokyo Institute of Technology, Japan. Worked on "Studies on Preparation and Electrocatalysis of Tantalum Oxide-Modified Electrodes" project.

2004–2008: Quality Control Officer, Essential Drugs Company Ltd., Dhaka, Bangladesh.

Relevant Publications

Amin, B.G.; Masud, J.; Nath, M. *RSC Adv.* **2019**, *9*, 37939–37946.

Masud, J. et al. *ACS Appl. Energy Mater.* **2018**, *1*, 4075.

Cao, X.; Hong, Y.; Zhang, N.; Chen, Q.; Masud, J.; Zaeem, M.A.; Nath, M. *ACS Catal.* **2018**, *8*, 8273.

Masud, J.; Ioannou, P.C.; Levesanos, N.; Kyritsis, P.; Nath, M. *Chem. Sus. Chem.* **2016**, *22*, 3128.

Masud, J.; Swesi, A.; Liyanage, W.P.R.; Nath, M. *ACS Appl. Mater. Interfaces* **2016**, *8*, 17292.

Masud, J.; Nath, M. *ACS Energy Lett.* **2016**, *1*, 27.

Swesi, A.; Masud, J.; Nath, M. *Energy Environ. Sci.* **2016**, *9*, 1771.

Masud, J. et. al. *J. Electrochem. Soc*. **2015**, *162* (4), F455.

Awaludin, Z.; Suzuki, M.; Masud, J.; Okajima, T.; Ohsaka, T. *J. Phys. Chem. C* **2011**, *115*, 25557.

Masud, J. et al. PRiME 2020 Meeting, Honolulu, HI, Oct 4–9, 2020, Accepted.

Synergistic Activities

2010 Best Collaboration Award, International Forum on Multidisciplinary Education and Research for Energy Science, Tokyo Institute of Technology Energy Global COE, Okinawa, Japan.
2020 Co-PI: Tunable CO_2 Electro-Valorization to High-Value Liquid Products, DOE, EERE (FOA DE-FOA-0002203).
Associate Editor, Energy and Thermofluids Engineering (ISSN 2716-8026).
Reviewer: ACS Appl. Mater. & Interfaces, Sci. Rep., Green Chemistry, Dalton Trans., Nanoscale etc.
Media Coverage: https://news.mst.edu/2016/12/16-important-research-stories-of-2016/.

MARK A. MUSICH
Research Engineer
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5263 (phone), 701.777.5181 (fax), mmusich@undeerc.org

Principal Areas of Expertise
Mr. Musich's principal areas of interest and expertise are the development and operation of high-pressure/high-temperature processes; gasification processes for syngas, hydrogen, and liquid fuels production; oxy-fuel and liquid and solid sorbent systems for CO_2 capture and purification; beneficiation processes including torrefaction, pyrolysis, agglomeration, hydrothermal and thermal treatment; chemical and physical cleaning for carbonaceous fuel upgrading; and the application of ionic liquids and deep eutectic solvents for production of value added products from coal, ash, and biomass residues.

Qualifications
M.S., Chemical Engineering, University of North Dakota, 1986.
B.S., Chemical Engineering, University of North Dakota, 1983.

PROFESSIONAL EXPERIENCE
2000–Present: Research Engineer, EERC, UND. Mr. Musich designs, procures, constructs, and operates high-pressure/high-temperature (HPHT) and other advanced conversion systems and performs experimental design and data evaluation and economic analysis of processes.

1996–2000: Research Manager, Systems Analysis, EERC, UND. Mr. Musich's responsibilities included supervision of Systems Analysis personnel; applying software engineering tools for the simulation and economic evaluation of chemical processes; performing critical review of SE studies; and applying SE methodology and decision-making tools to the design, development, and implementation of chemical processing technologies and systems.

1991–1996: Research Engineer/Supervisor, EERC, UND. Mr. Musich's responsibilities included experimental design and data evaluation, supervision of beneficiation and briquetting test programs, development of beneficiation processes, analytical and product evaluation techniques, beneficiation personnel supervision, preparation of reports and proposals, and preparation and presentation of papers.

1989–1991: Research Engineer, Fuels Beneficiation/Fuels Preparation, EERC, UND. Mr. Musich's responsibilities included the operation and maintenance of bench- and pilot-scale hydrothermal drying processes; operation of pilot-scale coal cleaning processes; design, performance, and evaluation of beneficiation experiments; report writing; and proposal solicitation.

1988–1989: Research Engineer, Mild Gasification, EERC, UND. Mr. Musich's responsibilities included the design and material specifications for the construction of a 100-lb/hr spout-fluid-bed reactor for the low-temperature gasification of carbonaceous feedstocks.

1986–1988: Contract Research Engineer, Great Plains Coal Gasification Company, Beulah, North Dakota. Mr. Musich's responsibilities included the operation and maintenance of a demonstration scale sour-gas scrubbing unit for the removal of SO_2, design of test matrices, evaluation of the test data, and preparation of reports.

1986–1987: Research Engineer, EERC, UND. Mr. Musich's responsibilities included the design, construction, and operation of a pilot-scale fluid-bed catalytic gasifier for the production of hydrogen from carbonaceous fuels.

1986: Engineering Research Technician, Combustion Division, EERC, UND. Mr. Musich's responsibilities included the operation of pilot-scale pulverized coal and fluidized-bed combustion units.

1985–1986: Engineer, EG&G Washington Analytical Services Center, Inc., Grand Forks, North Dakota. Mr. Musich's responsibilities included reviewing fluidized-bed combustion test data, isolating and evaluating steady-state performance periods, and performing mass and energy balances for the test periods.

Relevant Publications

Stanislowski, J.J.; Folkedahl, B.C.; Jensen, M.D.; Schlasner, S.M.; Wocken, C.A.; Patel, N.M.; Thakare, J.; Musich, M.A. *Subtask 2.3 – Support of DOE Carbon Capture Systems Develop-ment and Modeling*; Final Report for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FE0024233; 2019-EERC-03-01; Energy & Environmental Research Center: Grand Forks, ND, March 2019.

Laumb, J.D.; Kay, J.P.; Stanislowski, J.J.; Swanson, M.L.; Musich, M.A.; Curran, T.J.; Tolbert, S.G. *Pathway to Low-Carbon Lignite Utilization – Phases 1B and 2A*; Final Report for North Dakota Industrial Commission Contract No. FY16-LXXX-203; 2018-EERC-06-08; Energy & Environmental Research Center: Grand Forks, ND, June 2018.

Hussain, M.; Mann, M.D.; Swanson, M.L.; Musich, M.A. Testing of Lithium Silicate and Hydrotalcite as Sorbents for CO_2 Removal from Coal Gasification. In *Proceedings of the 24th Annual International Pittsburgh Coal Conference*; Johannesburg, South Africa, Sept 10–14, 2007.

Ruby, J.; Musich, M.A. CO_2 Separation, Capture, and Transport Technologies for CO_2 Reduction. In *Proceedings of the Western Fuels Symposium: 19th International Conference*; Billings, MT, Oct 12–14, 2004.

Synergistic Activities

34+ years of design, construction, and operation of bench/pilot-scale systems, i.e., processes for syngas purification, CO_2 capture, and H_2 separation; HPHT fluid-bed and entrained-flow gasifiers; hydrothermal processes for coal and biomass slurry-upgrading; and physical and chemical cleaning systems for coal upgrading.

Co-principal engineer for design, construction, and operation of 100-scfh solvent-based system for scrubbing CO_2 from stack gas of pilot-scale pulverized-coal combustion system. Procured equipment, developed P&ID, analyzed HAZOP, developed standard operating procedure (SOP), and trained personnel. Successful 1500+ hours of operation.

Co-lead engineer for relocating 100-scfh CO_2 scrubber system to stack of 450-MW lignite-fired utility boiler for slipstream testing. Developed equipment layout and plant utilities integration, P&ID, and SOP and trained personnel. Successful 4 months of continuous operation.

Principal design engineer for 50-lb/day solvent-based direct coal liquefaction system. Procured equipment, developed P&ID, analyzed HAZOP, developed SOP, and trained personnel. Successful multigallon production of jet fuel feedstock.

Applied chemical and physical cleaning, oil agglomeration, and hydrothermal treatment for preparation of low-ash fuels from lignite and subbituminous coals, i.e., design, construction, and operation of lab/bench/pilot-scale systems, including 7.5-tpd hot-water drying process development unit. Produced and rheologically evaluated combustion- and micronized-grind slurry fuels for firing in boilers, diesel engines, and turbine engines.

JASMINE L. OLEKSIK
Research Engineer, Fuels and Renewable Energy
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5374 (phone), 701.777.5181 (fax), joleksik@undeerc.org

Principal Areas of Expertise

Ms. Oleksik's principal areas of interest and expertise include chemical looping combustion, recovery of rare-earth elements from coal and coal by-products, and oil extraction for utilization in biofuels.

Qualifications

M.S., Chemical Engineering, University of North Dakota, 2020.
B.S., Chemical Engineering, University of North Dakota, 2017.
Proficient in the use of the following computer programs and simulation software: Microsoft Excel, Word, and PowerPoint; ChemCad; Visio; Ansys Fluent; Ventity; and Vensim.

Professional Experience

July 2018–Present: Research Engineer, Fuels and Renewable Energy, EERC, UND. Ms. Oleksik contributes to the design, modeling, and fabrication of experimental equipment; oversees and operates equipment; interprets data; helps to prepare proposals, reports, and papers; and presents project results to clients and at national and international conferences.

August 2016 – July 2018: Graduate Research Assistant, Department of Chemical Engineering, UND. Ms. Oleksik's work focused on the following:

- Transition of the strain of algae chlorella vulgaris from autotropic to heterotrophic growing conditions.
- Optimization of cracking lipids from the heterotrophic algae for utilization for biofuels and replace for petrochemicals.
- Optimization of the decomposition of glucose to form lactic acid derivatives and the transition of the optimal glucose decomposition conditions to xylose decomposition.
- Extraction of lipids from the heterotrophic algae for utilization for biofuels and replacements for petrochemicals.
- She also investigated solvent extraction optimization by employing the enhancement technique of microwave to aid in oil extraction.

May 2015–August 2016: Undergraduate Research Assistant, Department of Chemistry, UND. Ms. Oleksik evaluated methods for the extraction and chromatographic analysis of lignin decomposition products, performed preliminary experiments on metal catalyst screening, performed detailed kinetic experiments on the most promising catalysts, and worked on data presentation and interpretation.

Relevant Publications

Voeller, K.; Bilek, H.; Kreft, J.; Dostálková, A.; Kozliak, E.; Kubatova, A. Thermal Carbon Analysis Enabling Comprehensive Characterization of Lignin and Its Degradation Products. *ACS Sustainable Chem. Eng.* **2017**, *5* (11), 10334–10341; DOI: 10.1021/acssuschemeng.7b02392.

Pourjafar, S.; Kreft, J.; Bilek, H.; Kozliak, E.; Seames, W. Exploring Large Pore Size Alumina and Silica-Alumina Based Catalysts for Decomposition of Lignin. *AIMS Energy.* **2018**, 6 (6), 993-1008; DOI: 10.3934/energy.2018.6.993.

Kreft, J.; Moe, E.; Garcia, N.; Ross, A.; Seames, W. Comparative Scoping Study Report for the Extraction of Microalgae Oil from Two Subspecies of *Chlorella Vulgaris*. *Clean Energy Journal* **2020**, in press.

DR. DAISY F. SELVARAJ
Research Engineer
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5105 (phone), 701.777.5181 (fax), dselvaraj@undeerc.org

Principal Areas of Expertise

Dr. Selvaraj's principal areas of interest and expertise include grid integration of renewable energy resources, condition assessment of high-voltage apparatus, and use of machine learning algorithms/big data analytics for cyber physical systems.

Qualifications

Ph.D., Electrical Engineering, Visvesvaraya Technological University, Belagavi, India, 2018.

M.E., High-Voltage Engineering, College of Engineering Guindy, Anna University, Tamilnadu, India, 2008.

B.E., Electrical and Electronics Engineering, Bharathidasan University, India, 1999.

Software Skills

Electrostatic/electromagnetic field simulation using COMSOL Multiphysics 4.3, Integrated Coulomb 9.0; circuit simulation and programming in MATLAB; C, C++, Java 2.0, and ORACLE 8.0, Python and GAMS.

Laboratory/Instrumentation Skills

Frequency domain spectroscopy (FDS), polarization and depolarization current (PDC), partial discharge, insulation resistance, capacitance, and tan delta measurements; familiarity with national and international standards for testing of transformers and power cables.

Professional Experience

2019–Present: Research Engineer, EERC, UND. Dr. Selvaraj supports business development activities related to grid integration of renewable energy systems and batteries, smart grid, and asset management. Specific activities include identifying funding opportunities; developing proposals; and planning, leading, executing, and reporting on project tasks. In addition, Dr. Selvaraj teaches Electrical Engineering undergraduate courses in the UND Department of Electrical Engineering as well as providing academic advising and mentoring to students.

2018–2019: Postdoctoral Research Associate, School of Electrical Engineering & Computer Science, UND.

2017–2018: Assistant Professor, Department of Electrical and Electronics Engineering, Presidency University, Karnataka, India.

2013–2017: Senior Research Fellow, R&D Management Division, Central Power Research Institute, Karnataka, India.

2010–2013: Assistant Professor, Department of Electrical and Electronics Engineering, Rajiv Gandhi Institute of Technology, Karnataka, India.

2006–2008: Master's Degree Candidate, College of Engineering Guindy, Anna University, Tamilnadu, India.

2003–2006: Lecturer, Department of Electrical and Electronics Engineering, J.J College of Engineering and Technology, Tamilnadu, India.

2002: Production Engineer, Baby Industries, Tamilnadu, India.

2000–2001: Programmer, Sierratronic India Pvt. Limited, Tamilnadu, India.

Relevant Publications

Selvaraj, D.F.; Rajan, J.S. Experimental Simulation of Effects of High Temperatures on Paper Oil Insulation of Transformers in Presence of DBDS in Mineral Oil. *IEEE Trans. Dielectr. Electr. Insul.* **2017**, *24* (5), 2819–2827.

Rajan, J.S.; Selvaraj, D.F.; Ranganathaiah, C. Investigations on Copper Sulfide Diffusion into Paper Insulation of Transformers. *IEEE Trans. Dielectr. Electr. Insul.* **2016**, *23* (4), 2421–2429.

Selvaraj, D.F.; Rajan, J.S. A Study on Electrically Induced Thermal Effects on Dielectric Parameters of Paper Oil Insulation in Presence of DBDS. Presented at the 20th International Symposium on High Voltage Engineering, Argentina, Aug 28 – Sept 1, 2017, Paper ID 581.

Selvaraj, D.F.; Rajan, J.S. Modification of Electric Stress Distribution in Presence of Copper Ion in Paper Oil Insulation of Transformers. Presented at the 19th International Symposium on High Voltage Engineering, University of West Bohemia, Pilsen, Czech Republic, Aug 23–28, 2015, Paper ID 485.

Selvaraj, D.F.; Kanyakumari, M.; Rajan, J.S. Study of Modification of Electric Field Distribution in Paper-Oil Insulation of Transformer in the Presence of Copper Sulphide. Presented at the IEEE International Conference on Liquid Dielectrics, Bled, Slovenia, June 30 – July 3, 2014, Paper ID 192.

Synergistic Activities

Reviewer, U.S. Department of Energy Artificial Intelligence and Decision Support for Complex System Review, July 2020.

Session Chair. Special Session on Electric Vehicles, Emerging Topics Track, 2019 North American Power Symposium (NAPS), Wichita, KS, October 2019.

Reviewer, 2019 NAPS, Wichita, KS, October 2019.

Reviewer, IEEE Wireless Communications Magazine, IEEE Access, Elsevier Thermal Science and Engineering Progress, and Elsevier Corrosion Science.

Member, Institute of Electrical and Electronics Engineers (IEEE).

APPENDIX C

BUDGET NOTES

BUDGET JUSTIFICATION

ENERGY & ENVIRONMENTAL RESEARCH CENTER (EERC)

BACKGROUND

The EERC is an independently organized multidisciplinary research center within the University of North Dakota (UND). The EERC is funded through federal and nonfederal grants, contracts, and other agreements. Although the EERC is not affiliated with any one academic department, university faculty may participate in a project, depending on the scope of work and expertise required to perform the project.

INTELLECTUAL PROPERTY

The applicable federal intellectual property (IP) regulations will govern any resulting research agreement(s). In the event that IP with the potential to generate revenue to which the EERC is entitled is developed under this project, such IP, including rights, title, interest, and obligations, may be transferred to the EERC Foundation, a separate legal entity.

BUDGET INFORMATION

The proposed work will be done on a cost-reimbursable basis. The distribution of costs between budget categories (labor, travel, supplies, equipment, etc.) and among funding sources of the same scope of work is for planning purposes only. The project manager may incur and allocate allowable project costs among the funding sources for this scope of work in accordance with Office of Management and Budget (OMB) Uniform Guidance 2 CFR 200.

Escalation of labor and EERC recharge center rates is incorporated into the budget when a project's duration extends beyond the university's current fiscal year (July 1 – June 30). Escalation is calculated by prorating an average annual increase over the anticipated life of the project.

The cost of this project is based on a specific start date indicated at the top of the EERC budget. Any delay in the start of this project may result in a budget increase. Budget category descriptions presented below are for informational purposes; some categories may not appear in the budget.

Salaries: Salary estimates are based on the scope of work and prior experience on projects of similar scope. The labor rate used for specifically identified personnel is the current hourly rate for that individual. The labor category rate is the average rate of a personnel group with similar job descriptions. Salary costs incurred are based on direct hourly effort on the project. Faculty who work on this project may be paid an amount over the normal base salary, creating an overload which is subject to limitation in accordance with university policy. As noted in the UND EERC Cost Accounting Standards Board Disclosure Statement, administrative salary and support costs which can be specifically identified to the project are direct-charged and not charged as facilities and administrative (F&A) costs. Costs for general support services such as contracts and IP, accounting, human resources, procurement, and clerical support of these functions are charged as F&A costs.

Fringe Benefits: Fringe benefits consist of two components which are budgeted as a percentage of direct labor. The first component is a fixed percentage approved annually by the UND cognizant audit agency, the Department of Health and Human Services. This portion of the rate covers vacation, holiday, and sick leave (VSL) and is applied to direct labor for permanent staff eligible for VSL benefits. Only the actual approved rate will be charged to the project. The second component is estimated on the basis of historical data and is charged as actual expenses for items such as health, life, and unemployment insurance; social security; worker's compensation; and UND retirement contributions.

Travel: Travel may include site visits, fieldwork, meetings, and conferences. Travel costs are estimated and paid in accordance with OMB Uniform Guidance 2 CFR 200, Section 474, and UND travel policies, which can be found at http://und.edu/finance-operations (Policies & Procedures, A–Z Policy Index, Travel). Daily meal rates are based on U.S. General Services Administration (GSA) rates unless further limited by UND travel policies; other estimates such as airfare, lodging, ground transportation, and miscellaneous costs are based on a combination of historical costs and current market prices. Miscellaneous travel costs may include parking fees, Internet charges, long-distance phone, copies, faxes, shipping, and postage.

Equipment: If equipment (value of $5000 or more) is budgeted, it is discussed in the text of the proposal and/or identified more specifically in the accompanying budget detail.

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.

Subcontracts: Vetri Labs will be contracted to assist EERC in all aspects of project, including providing guidance on MEA fabrication for 1-step NH3 synthesis, and development and assessment of NH3-BEST performance improvement and cost reduction strategies.

Professional Fees: Not applicable.

Communications: Telephone, cell phone, and fax line charges are included in the F&A cost; however, direct project costs may include line charges at remote locations, long-distance telephone charges, postage, and other data or document transportation costs that can be directly identified to a project. Estimated costs are based on prior experience with similar projects.

Printing and Duplicating: Page rates are established annually by the university's duplicating center. Printing and duplicating costs are allocated to the appropriate funding source. Estimated costs are based on prior experience with similar projects.

Food: Expenditures for project partner meetings where the primary purpose is dissemination of technical information may include the cost of food. The project will not be charged for any costs exceeding the applicable GSA meal rate. EERC employees in attendance will not receive per diem reimbursement for meals that are paid by project funds. The estimated cost is based on the number and location of project partner meetings.

Professional Development: Fees are for memberships in technical areas directly related to work on this project. Technical journals and newsletters received as a result of a membership are used throughout the development and execution of the project by the research team.

Operating Fees: Operating fees generally include EERC recharge centers, outside laboratories, and freight.

EERC recharge center rates are established annually and approved by the university.

Laboratory and analytical recharge fees are charged on a per-sample, hourly, or daily rate. Additionally, laboratory analyses may be performed outside the university when necessary. The estimated cost is based on the test protocol required for the scope of work.

Graphics recharge fees are based on an hourly rate for production of such items as report figures, posters, and/or images for presentations, maps, schematics, Web site design, brochures, and photographs. The estimated cost is based on prior experience with similar projects.

Shop and operations recharge fees cover specific expenses related to the pilot plant and the required expertise of individuals who perform related activities. Fees may be incurred in the pilot plant, at remote locations, or in EERC laboratories whenever these particular skills are required. The rate includes such items as specialized safety training, personal safety items, fall protection harnesses and respirators, CPR certification, annual physicals, protective clothing/eyewear, research by-product disposal, equipment repairs, equipment safety inspections, and labor to direct these activities. The estimated cost is based on the number of hours budgeted for this group of individuals.

Engineering services recharge fees cover specific expenses related to retaining qualified and certified design and engineering personnel. The rate includes training to enhance skill sets and maintain certifications using Webinars and workshops. The rate also includes specialized safety training and related physicals. The estimated cost is based on the number of hours budgeted for this group of individuals.

Software solutions services recharge fees are for development of customized Web sites and interfaces, software applications development, data and financial management systems for comprehensive reporting and predictive analysis tools, and custom integration with existing systems. The estimated cost is based on prior experience with similar projects.

Freight expenditures generally occur for outgoing items and field sample shipments.

Facilities and Administrative Cost: The F&A rate proposed herein is approved by the U.S. Department of Health and Human Services and is applied to modified total direct costs (MTDC). MTDC is defined as total direct costs less individual capital expenditures, such as equipment or software costing $5000 or more with a useful life of greater than 1 year, as well as subawards in excess of the first $25,000 for each award.