STATE ENERGY RESEARCH CENTER ANNUAL REPORT

Annual Report

Submitted to:

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EERC DISCLAIMER

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EXECUTIVE SUMMARY

The University of North Dakota (UND) Energy & Environmental Research Center (EERC) was designated the State Energy Research Center (SERC) by the 66th Legislative Assembly of North Dakota through SB2249. SERC is built on the reputation of the EERC as a leader in critical energy research, with the purpose of serving the state of North Dakota by developing technologies to ensure a prosperous energy future for North Dakota. Thomas Erickson, then CEO of the EERC, stated the following during testimony for SB2249:

> "The EERC has demonstrated that we are a critical component advancing energy for the state of North Dakota, the industries and utilities operating in North Dakota, and the citizens of North Dakota. We are asking for your support of Bill 2249, providing us the opportunity to enhance our service to North Dakota through the establishment and funding of the State Energy Research Center. Although the return on investment of this funding may be difficult to quantify, as evidenced by past performance, the benefits of these efforts will be orders of magnitude greater than the investment."

The availability of commercially deployable technologies and concepts to serve the state in the future is dependent on continually creating innovative ideas. As shown in Figure ES-1, exploratory research is the first step in the process toward commercialization. Exploratory research feeds research and development, eventually leading to demonstration and commercialization.

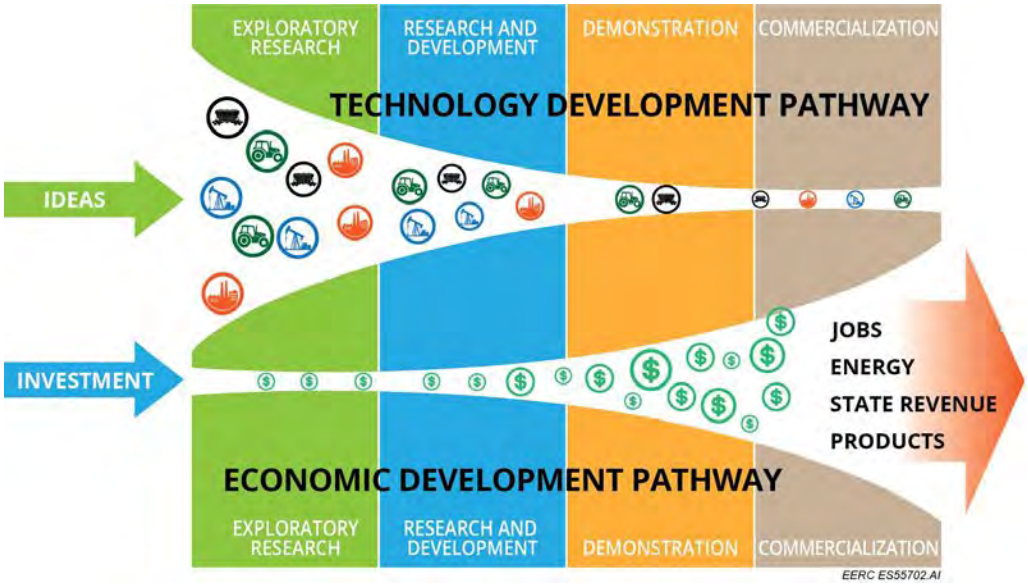

Figure ES-1. SERC funding is focused on accelerating exploratory research to generate new ideas and concepts. Those concepts are then advanced through additional research and development, demonstration, and commercialization with separate funding sources.

As described below, the first year of SERC activities has resulted in:

- A significant increase in exploratory research.
- Research activities across all facets of North Dakota energy.
- A large increase in the number of new inventions.
- Initiation of the first phase of a statewide energy sustainability study.
- 20 North Dakota students participating in the Energy Hawks Program.
- Greater collaboration across the state's institutions of higher education.

Establishment of the State Energy Research Center

As stated within SB2249, SERC was established to allow the EERC to conduct exploratory, transformational, and innovative research that advances future energy opportunities and benefits the state's economy and environment through:

- Exploratory research of technologies and methodologies that facilitate the prudent development, and clean and efficient use, of the state's energy resources.

- Greater access to energy experts for timely scientific and engineering studies to support the state's interests.

- Education and outreach related to the state's energy resources.

Funding for SERC, up to $5 million per biennium, is provided from a small portion of the oil and gas production and extraction taxes. The first biennium's funding was completely allocated to SERC activities by February of 2020. SERC funding is currently set to expire after two biennia, on June 30, 2023.

Accelerating Exploratory Research

Upon initiating SERC efforts, the EERC implemented a five-step innovation process to accelerate exploratory research and serve the state of North Dakota by developing new technology concepts. This process is designed to increase researcher productivity while decreasing unnecessary administrative burden and has successfully generated a broad suite of new concepts in the first year of SERC activities. Only a select number these concepts were ultimately chosen for funding. The five-step process included:

1) Conducting brainstorming sessions to generate innovative research ideas.

2) Reviewing ideas using teams of technical and nontechnical research experts to assess the concepts and support their selection.

3) Working with selected projects to optimize their research plan for service to North Dakota.

4) Conducting exploratory research.

5) Identifying additional funding sources to further the research and development of completed projects and, when appropriate, through demonstration and commercialization, as noted in Figure ES-1.

Innovation Is Born

Within the first year of SERC activities, the EERC has seen a significant new focus on exploratory research with a variety of projects touching all facets of North Dakota energy. All $5 million available for the biennium was allocated to projects within the first year. Fifty-nine innovative research concepts were brought forward for potential funding from SERC in three rounds of internal solicitation. Rounds 1 and 2 followed the approach noted above. Round 3, which occurred during remote operations resulting from COVID-19 and had significantly less funding available because of the tremendous ideas already funded, was carried out in a slightly abbreviated manner of the same process. Figure ES-2 shows the number of innovative concepts proposed during each round and the number of projects chosen to move forward.

Figure ES-2. Fifty-nine concepts were brought forward for consideration within the first year of SERC efforts. Through significant vetting, 25 were chosen for funding.

Through significant vetting of the proposed concepts via a peer-led review process (tiger team method), 25 new research projects were selected. The selected projects focused on coal, oil and gas, and renewable energy and included methods of optimized extraction and utilization, critical element extraction, new materials, and environmental protection. A diagram representing the breakdown of areas funded is shown in Figure ES-3. While it was originally envisioned that projects would be selected in stages throughout the biennium, the significant number of ideas brought forth during the innovation process resulted in 100% of the exploratory research funding being allocated within the first year.

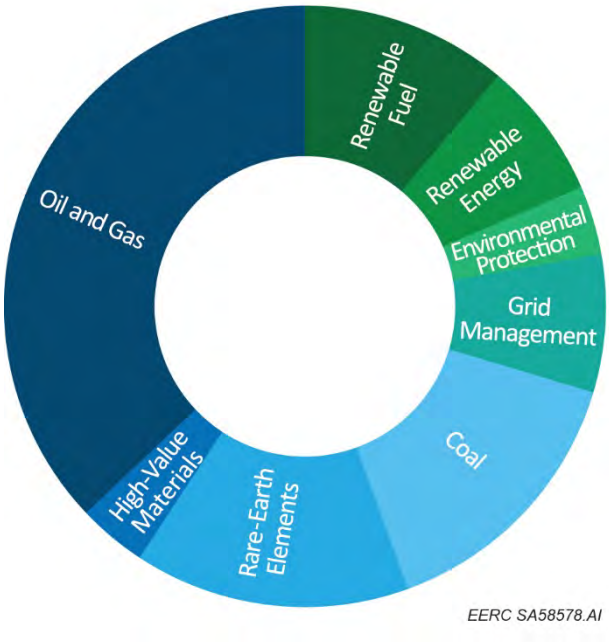

Figure ES-3. Breakdown of areas funded within the exploratory research component of SERC.

Of the 25 research projects initiated, seven projects were completed within the first year of SERC activities. It should be noted that all of these projects are in the exploratory stages of research and significant additional work is necessary to advance the concepts developed. Some of the highlights from those projects include the following:

- Production of the first-ever graphene dot from North Dakota lignite. Graphene is a high-value, high-strength material produced from uniquely arranged carbon molecules. North Dakota lignite has attributes that may make graphene production advantageous.

- A significant analysis was completed on the most efficient and least cost process for conversion of wellhead gas to transportable liquid products.

- Energy storage technologies for use in North Dakota were analyzed, and three technologies were modeled as part of a more detailed analysis.

- Limited research has identified areas within North Dakota shales for potential recovery of rare-earth elements and other critical metals.

- Potential areas of grid vulnerability from naturally occurring electromagnetic pulses were identified.

- Laboratory efforts tested a conceptual in situ method for extracting rare-earth elements from coal.

- The effect of stress shadows on hydraulic fracture development and the optimization of fracture spacing for Bakken wells were investigated.

Primarily as a result of innovative research funded through SERC, the EERC has seen a significant increase in the number of new invention disclosures, as shown in Figure ES-4. Prior to SERC funding, as noted within the testimony supporting SB2249, the EERC had seen a dramatic decrease in new inventions, with 2018 recording zero invention disclosures. The new inventions resulting from SERC projects are currently being examined for legal protection through patenting and other less formal forms of protection.

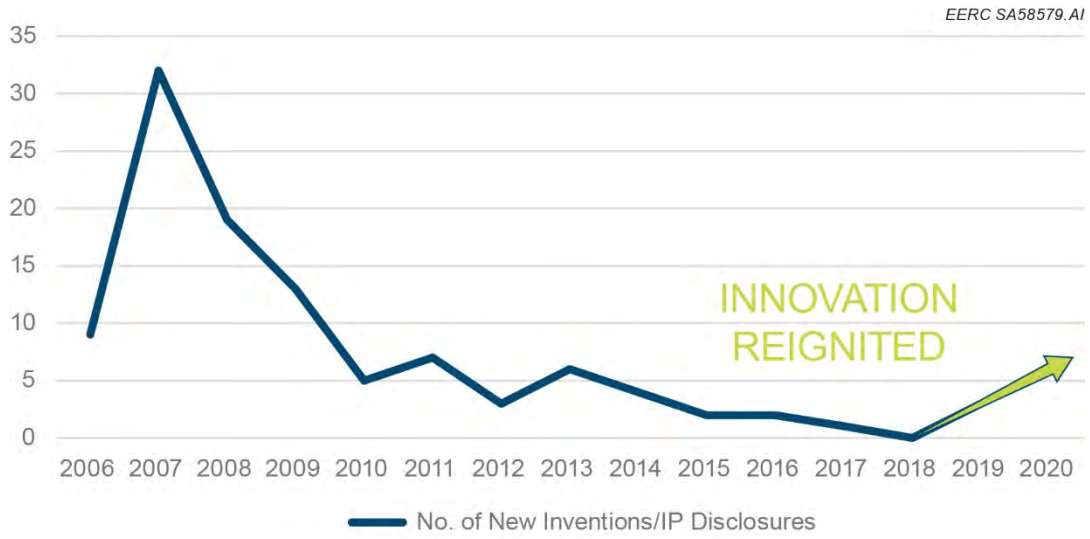

Figure ES-4. The EERC has seen a significant increase in invention disclosures in the first year of SERC activities.

North Dakota's Energy Future

The second focus area of SERC is on providing greater access to energy experts for timely scientific and engineering studies. On April 1, 2020, the North Dakota Industrial Commission (NDIC) approved a SERC-funded project focused on identifying the challenges and opportunities related to achieving energy sustainability for the state of North Dakota within the next 5 to 20 years.

North Dakota's energy industries are constantly adjusting to meet the future environmental, social, and economic needs of its citizens. The state of North Dakota, while continuing an all-of-the-above energy approach, needs to be prepared for transitions in the energy industries that will affect issues such as 1) ensuring affordable, dispatchable energy is available for North Dakota citizens; 2) maintaining existing and expanding future employment opportunities; 3) maintaining North Dakota's healthy environment; and 4) maintaining state, tribal, and local tax revenues.

Within this project, one of the goals is identifying and quantifying relationships between the various components of North Dakota's energy industry and the objective of maintaining and growing jobs and revenues, maintaining a healthy environment, and ensuring affordable and reliable access to energy. Figure ES-5 is a first-generation conceptual model, developed through this effort, which shows the relationships between various components considered in the study.

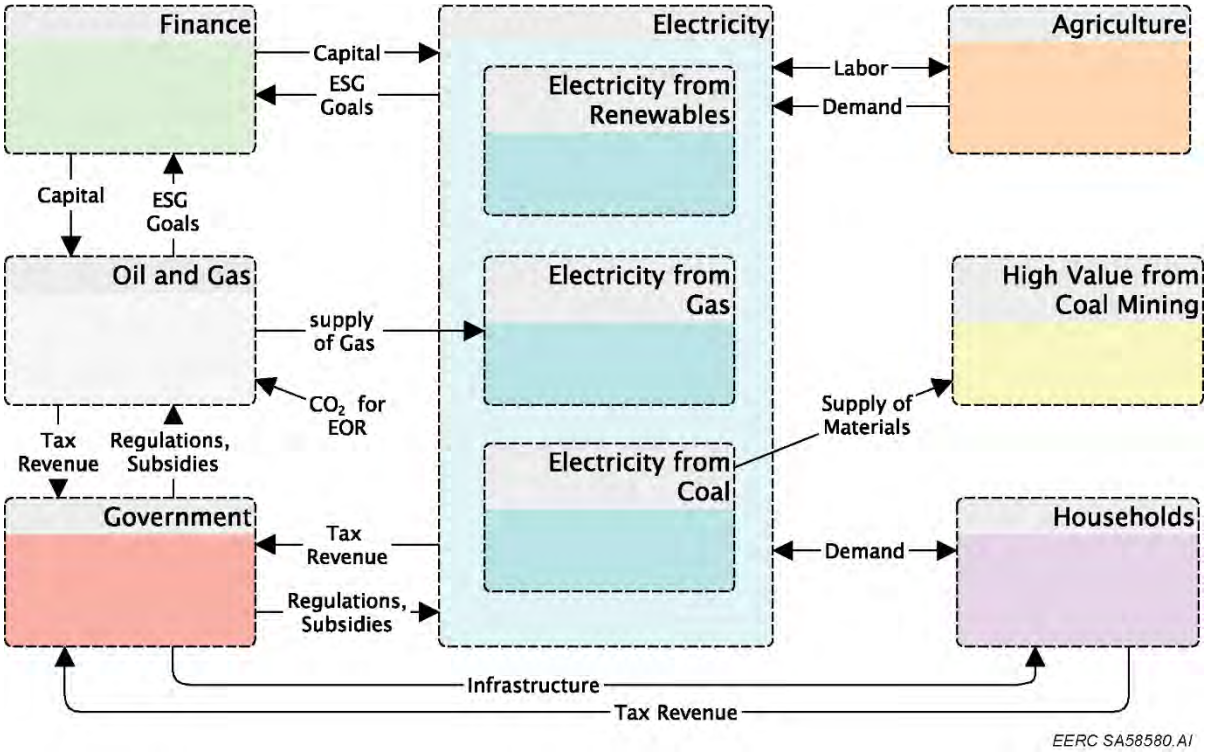

Figure ES-5. Identifying the critical relationships between North Dakota's energy sectors, the state, and citizens of North Dakota.

This project, planned to be completed by the end of 2020, will develop a series of small models that allow us to understand the relationships between the critical components of North Dakota's energy and other industries. These small models, along with other research activities and discussions with industry experts, state leaders, and other stakeholders, will be used to develop options to help ensure sustainability in accordance with the project's direction. This effort is considered Phase I of a much larger vision to develop a more comprehensive approach to ensuring sustainability.

Providing Opportunities and Resources for Education and Outreach

Within the education and outreach component of SERC, both the 2019 and 2020 Energy Hawks Programs were conducted. The multidisciplinary Energy Hawks Program brings together students from a variety of academic programs to collaborate on identifying value-added opportunities for North Dakota energy. Students spend 10 weeks learning about all forms of North Dakota energy, including a weeklong tour of western North Dakota to visit oil and gas, coal, ethanol, hydro, and wind sites. The 2019 Energy Hawks produced three concept papers with ideas to help add value to North Dakota energy.

The Energy Hawks Program for 2020 is being conducted in a remote, online manner because of COVID-19 safety measures (Figure ES-6). One student from North Dakota State University and one student from Bismarck State College joined nine University of North Dakota students for this year's program. The 2020 program will be completed in early August with three concept papers prepared by the students, similar to previous Energy Hawk years.

Figure ES-6. 2020 Energy Hawks participating entirely remotely.

To better foster statewide energy education and outreach, a meeting was held on July 31, 2019, at the EERC to discuss opportunities for collaboration across all institutions of higher education within the state of North Dakota. The invitation to participate went to all institutions across North Dakota and was not limited to those within the State Board of Higher Education. Based on discussions during the July meeting, a web-based system allowing access to energy-related education and outreach information from the participating institutions was created. The online E-Portal system serves as a one-stop shop for education and outreach information already existing within the different institutions. Figure ES-7 shows the concept of providing information and the participating institutions to date. The E-Portal system, www.ndportal.org, went live in June 2020.

Figure ES-7. Graphic showing an overview of the E-Portal concept and current participating institutions.

Future Efforts

The overall efforts of SERC will continue into the second year of the biennium, with significant work progressing on activities that have already commenced; however, no new projects are anticipated to be funded, as all $5 million available for the biennium was allocated within the first year. Although 25 new research projects were successfully funded, 59 innovative research concepts were brought forth by EERC researchers in the first year alone, with numerous additional ideas in discussion should additional funding become available. As appropriate, results will be presented to NDIC, the Energy Development and Transmission Committee, and the next North Dakota legislative body.

STATE ENERGY RESEARCH CENTER ANNUAL REPORT

INTRODUCTION

North Dakota is blessed with abundant energy opportunities (including coal, oil and gas, wind, biofuels, and solar), exceptional agricultural production, and a highly skilled workforce. Collectively, these attributes contribute to the state being among the most productive per capita in the nation. To keep North Dakota globally competitive while focusing on resource and environmental stewardship, new and more efficient energy production technologies and methods are needed. This includes innovative energy and agricultural synergies and the creation of new value-added products from raw materials and energy by-products/wastes. Recognizing this need, the North Dakota Legislative Assembly named the Energy & Environmental Research Center (EERC) the State Energy Research Center (SERC) of North Dakota.

The University of North Dakota (UND) EERC was designated SERC by the 66th Legislative Assembly of North Dakota through SB2249. SERC is built on the reputation of the EERC as a leader in critical energy research, with the purpose of serving the state of North Dakota by developing technologies to ensure a prosperous energy future for North Dakota.

The availability of commercially deployable technologies and concepts to serve the state in the future is dependent on continually creating innovative ideas. As shown in Figure 1, exploratory research is the first step in the process toward commercialization. Exploratory research feeds research and development, eventually leading to demonstration and commercialization.

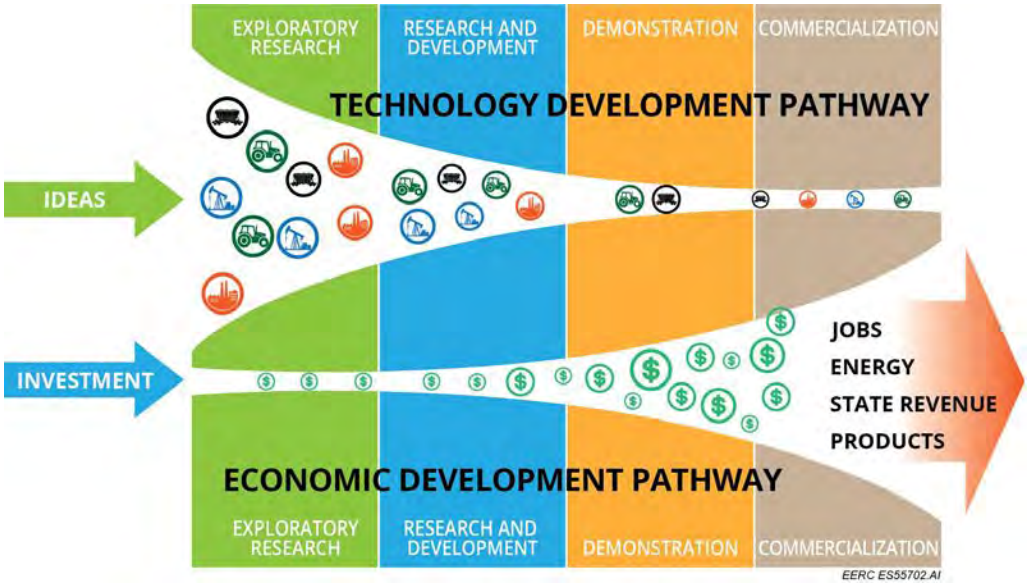

Figure 1. SERC funding is focused on accelerating exploratory research to generate new ideas and concepts. Those concepts are then advanced through additional research and development, demonstration, and commercialization with separate funding sources.

Prior to the establishment of SERC, the EERC had realized a significant decrease in available funding for exploratory research. Prior to 2011, federally directed funding ("earmarks") was available that allowed exploratory research on a wide variety of research projects. This exploratory research resulted in innovative concepts as evidenced by the number of new invention disclosures at the EERC during that time. Unfortunately, after federally directed funding was discontinued, new inventions significantly decreased, as shown in Figure 2. The lack of funding for exploratory research directly led to the decrease in new inventions, resulting in zero new invention disclosures in 2018 (Figure 2). This dramatic reduction in the ability to conduct exploratory research stifled the development of new concepts and ideas to support the future of North Dakota.

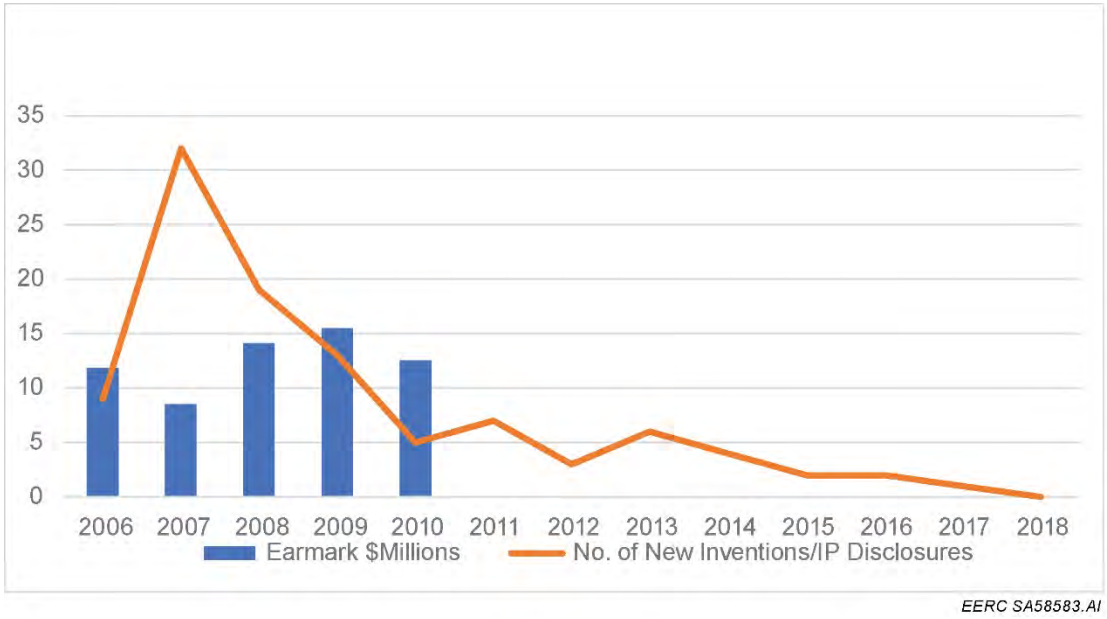

Figure 2. The EERC realized a significant decline in new inventions as funding for exploratory research decreased.

As stated within SB2249 (full bill is shown in Appendix B), SERC was established to support the EERC in conducting exploratory, transformational, and innovative research that advances future energy opportunities and benefits the state's economy and environment through:

- Exploratory research of technologies and methodologies that facilitate the prudent development, and clean and efficient use, of the state's energy resources.
- Greater access to energy experts for timely scientific and engineering studies to support the state's interests.
- Education and outreach related to the state's energy resources.

Funding for SERC, up to $5 million per biennium, is provided from a small portion of the oil and gas production and extraction taxes. The first biennium's funding was completely allocated

to SERC activities by February of 2020. SERC funding is currently set to expire after two biennia, on June 30, 2023.

SERC was given the mandate to provide practical, pioneering technologies and methods to support North Dakota's energy opportunities and benefit the state's economy and environment. Three corresponding work tasks were created to execute SERC objectives:

- Task 1 – Perform Exploratory Research for North Dakota Energy
- Task 2 – Provide Prompt Expertise for North Dakota
- Task 3 – Advocate and Educate Through Outreach

This report provides an update on SERC activities conducted over the past year across these three tasks.

TASK 1 ANNUAL SUMMARY

SERC is conducting multiple projects under this task, each focused on early-stage, exploratory energy research topics with the potential to positively impact North Dakota, its industries, and its citizens. Emphasis is placed on technology and strategy development that could ultimately lead to commercial application with public and private sector partners.

The EERC implemented a five-step innovation process to accelerate exploratory research and serve the state of North Dakota by developing new technology concepts. This process is designed to increase researcher productivity while decreasing unnecessary administrative burden and has successfully generated a broad suite of new concepts in the first year of SERC activities. Only a select number these concepts were ultimately chosen for funding. The five-step process included:

1) Conducting brainstorming sessions to generate innovative research ideas.

2) Reviewing ideas using teams of technical and nontechnical research experts to assess the concepts and support their selection.

3) Working with selected projects to optimize their research plan for service to North Dakota.

4) Conducting exploratory research.

5) Identifying additional funding sources to further the research and development of completed projects and, when appropriate, through demonstration and commercialization.

With the above steps serving as a framework, 59 fundamental research concepts were identified and evaluated this past year, with 25 projects ultimately selected for SERC funding. The

25 selected projects are listed below. Seven of the funded projects, denoted with an *, were completed during the last year and are summarized below.

- Critical Minerals Assessment of North Dakota Shales*
- Evaluation of High-Value Solid Carbon Products from North Dakota Lignite*
- Power Production and Distribution Resilience to Electromagnetic Pulses*
- Identification of the Most Efficient and Least Cost Process for Conversion of Wellhead Gas to Transportable Liquid Products*
- Evaluation of Energy Storage Technologies and the Benefit to North Dakota Utilities*
- Solvent Extraction of Rare-Earth Elements from Lignite Coal In Situ*
- Waste Utilization for Bio-Based Alternatives to Chemicals and Fuels
- Crude Oil Swelling with Injected Rich Gas and CO_2 as a Potential Mechanism for Enhanced Oil Recovery in the Bakken
- Enhancing Reservoir Productivity Through a New Hydraulic Fracturing Approach*
- Bench-Scale Extraction of Rare-Earth Elements from Lignite Coal Ash
- Corn Oil Extraction Efficiency Optimization
- Subsurface Pressure Management: Managing the Inyan Kara Formation while Drilling
- North Dakota Wind Turbine Blade Recycling
- Developing Value in North Dakota's Produced Geologic Brines
- Evaluating Shared Border Analysis for Classifying Unconventional Reservoirs in North Dakota
- Rare-Earth Elements and Graphene Precursors from North Dakota Lignite Prepared Using Ionic Liquids
- Electrochemical Pathways for Enhanced Ethanol Synthesis at Near-Zero Emission
- Exploration of Opportunities and Challenges for a North Dakota Petrochemical Industry
- Enhancing Stimulated Reservoir Volume Through a New Refracturing Approach
- Toward a Real-Time Detection of Buried Pipelines and Spills in North Dakota
- Hosting Capacity Analysis for Improved Planning and Operations of North Dakota Distribution Networks

- Silica Nanoparticles from North Dakota Lignite Fly Ash
- Novel Concepts in Support of Lignite Coal
- Analytical Analysis of Gas Injection EOR in the Bakken and Measuring Injected Gas Penetration Rates into Bakken Rock Cores
- Laboratory Proof of Concept of Microbubble CO_2 and Microbubble Rich Gas Enhanced Oil Recovery for Application in North Dakota Oil Plays

Primarily as a result of innovative research funded through SERC, the EERC has seen a significant increase in the number of new invention disclosures, as shown in Figure 3. Prior to SERC funding, as noted within the testimony supporting SB2249, the EERC had seen a dramatic decrease in new inventions, with 2018 recording zero invention disclosures. Six new invention disclosures were submitted by EERC researchers in FY20, as driven by SERC funding. The new inventions resulting from SERC projects are currently being examined for legal protection through patenting and other less formal forms of protection.

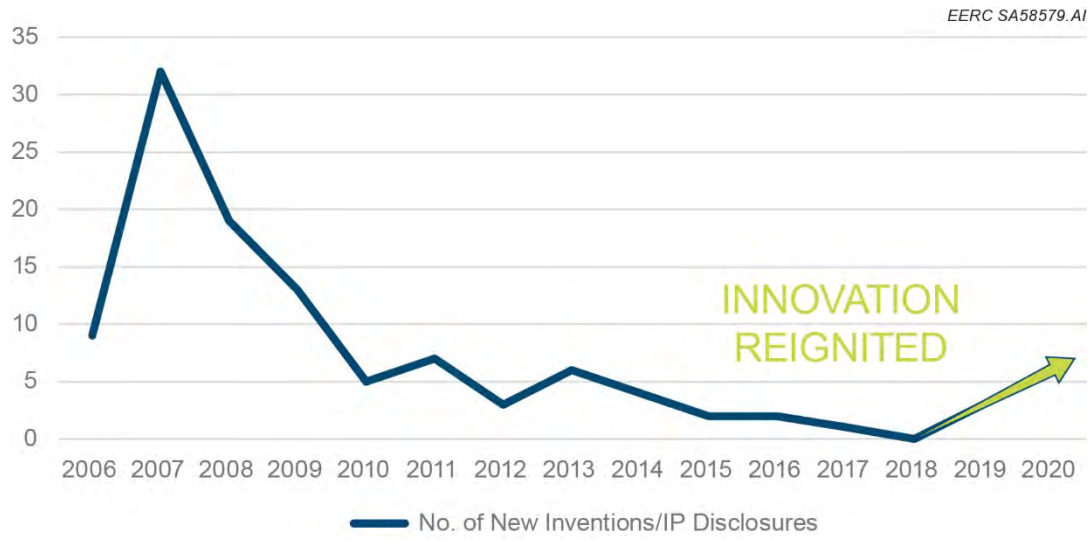

Figure 3. The EERC has seen a significant increase in invention disclosures in just the first year of SERC activities.

Critical Minerals Assessment of North Dakota Shales

Overview

North Dakota shales were studied for their potential as a source of rare-earth elements (REEs). The concentrations of REEs and several other critical minerals present in North Dakota shales were determined. The goals of this project were to 1) identify shale resources in the state of North Dakota that have elevated levels of critical minerals and 2) better understand the thermal maturity and depositional environment of the source rock using the identified critical minerals.

Highlights

- 78 North Dakota shale samples were evaluated for total REE (TREE) and other critical material (CM) content. This includes 31 Niobrara and 12 Pierre Formation samples collected with the help of the North Dakota Geological Survey, as well as 35 Bakken sample analyses generated under a separate project.

- Results showed that a relatively high percentage (9.3%) of the 43 Niobrara and Pierre samples had TREE levels >300 ppm, which is more than double the percentage found in a coal characterization project conducted by the EERC in 2019 (17 of 475 lignite samples from 13 seams for 3.6%).

- Elemental analysis of several other CMs (i.e., antimony, barium, cobalt, chromium, copper, gallium, lithium, manganese, molybdenum, nickel, niobium, rubidium, strontium, vanadium, zinc, and zirconium) showed promising levels averaging between 10 and 4000 ppm.

- Spatial distribution of samples across the shales shows potential of higher TREE levels in the Niobrara to be present across the formation. The Bakken samples, while lower in TREE concentration, show consistent levels across their spatial distribution (Figure 4). Additional sampling and analysis from other locations are recommended to better understand the spatial distribution of TREEs.

- In addition to evaluating shales as a potential CM resource, many of the characterized metals can serve as key indicators of the paleodepositional environment of the various formations. Although the data set may be too small to draw definitive conclusions, there appears to be enough of a trend to warrant further studies that include redox-sensitive metals analysis in conjunction with other thermal maturity indices.

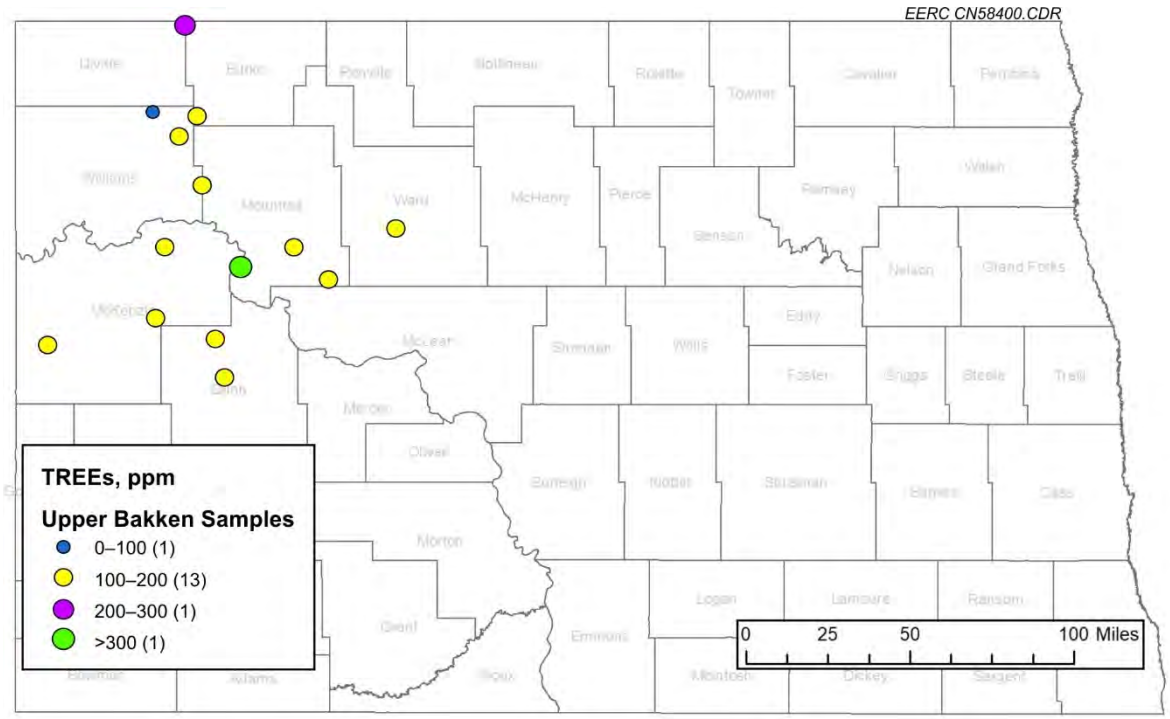

Figure 4. Spatial distribution of TREE concentration in Upper Bakken samples.

Next Steps

- Follow-on work with two components is being considered:

  – A more comprehensive study of North Dakota shales with a broader distribution across the state. In this phase, the number of samples collected would be increased, and the list of CMs analyzed would be reduced to focus on those that were found at elevated levels.

  – Correlating redox-sensitive proxy metals (i.e., chromium, cobalt, copper, molybdenum, nickel, vanadium, and uranium) with organic petrology parameters such as total organic carbon and vitrinite reflectance. Initial results showed correlation between redox metals and organic carbon. However, the data set was too small to be statistically valid. These indicators combined can help determine the thermal maturity and depositional environment of the geologic formations.

Evaluation of High-Value Solid Carbon Products from North Dakota Lignite

Overview

Graphene is a very valuable and difficult to produce material with unique physical properties. This study focused on developing a lignite-to-graphene (L2G) technology. The L2G process evaluated options to improve North Dakota lignite coal through EERC-developed

advanced cleaning methods and novel transformations to upgrade the cleaned product into an enhanced lignite graphene precursor, which can then be used to make graphene.

Highlights

- North Dakota lignite samples from the Center, Freedom, and Falkirk Mines were evaluated.
- The world's first graphene quantum dots (GQDs) from North Dakota lignite were created. Ultraviolet fluorescence was used to confirm the presence of GQDs derived from Freedom, Falkirk, and Center lignite (Figure 5).
- Additional experiments aimed at reducing the heteroatom content of the coal were successful, improving the quality of North Dakota lignite as a graphene precursor.
- A new system for low-pressure, entrained-coal chemical vapor deposition was designed, assembled, and tested for making layered graphene. Although carbon films were successfully made with this system, the results are preliminary, and the system will be further investigated for additional improvements and optimization of process conditions.

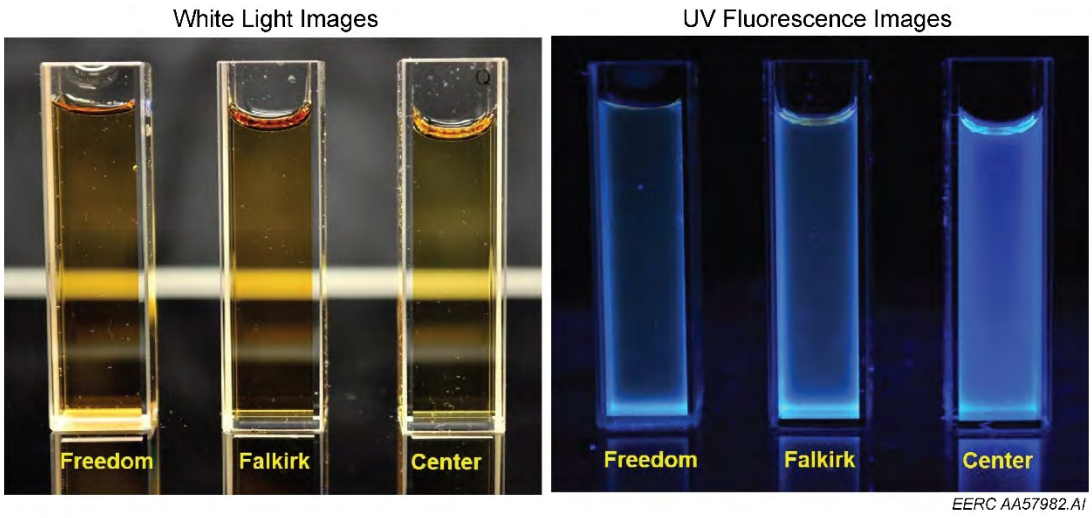

Figure 5. North Dakota lignite-derived GQD solutions under white light (left) and UV fluorescence (right).

Next Steps

- Additional funding has been secured via the U.S. Department of Energy (DOE) and the North Dakota Industrial Commission Lignite Research Program (NDIC LRP) to continue exploratory work on lignite and other U.S. coals.

- A Phase II project is being considered to further develop a novel method for making graphene layers from North Dakota Lignite (separate from the current DOE-funded project).

- Project results are being used to support another proposal application to the Army Corps of Engineers.

Power Production and Distribution Resilience to Electromagnetic Pulses

Overview

Naturally occurring electromagnetic pulses (EMPs) are a significant threat to the grid. This project developed a pathway to identify and address weaknesses in power production and distribution caused by naturally occurring EMPs in North Dakota. This goal was met by conducting a literature search to acquire information on the current status of EMP protection and legislation; developing a database of technologies currently in use; and engaging with researchers at the University of North Dakota (UND), the Grand Forks Air Force Base, and representatives from North Dakota utilities to determine a hierarchy of needs and identify areas of EMP susceptibilities.

Highlights

- Discussions were held with prominent regional groups such as Minnkota Power Cooperative, Basin Electric Power Cooperative, the Nebraska Public Power District, the Grand Forks Air Force Base, and the Midcontinent Independent System Operator (MISO).

- A list of available technologies and services related to EMP protection was compiled.

- Improved modeling capability is needed to identify failure points within interdependent networks, which, in turn, can help identify and prove which components of the grid are the most critical pieces of infrastructure and promote mitigation and protection approaches. A portion of the grid in North Dakota could be used as a small case study to understand what the effects of an EMP might be to the power generation and transmission system.

- Because of the sensitive nature of this topic, it can be difficult to establish lines of communication between organizations. It is recommended that better communication be established between entities at the regional and federal levels. These groups could include the EERC, agencies of the North Dakota state government, electrical generators, and electrical utilities and operators. Establishing a communication network would enable a better understanding of potential vulnerabilities in the electrical grid of North Dakota. This could help inform the state of North Dakota and the power industry in allocating resources and time to address these potential issues in an efficient and effective manner.

Next Steps

- Discussions have continued with the MISO organization regarding potential collaboration.

- Discussions have continued with Grand Forks Emergency Management, with support provided for updating the Grand Forks County multihazard mitigation plan.

- Federal funding opportunities are being pursued to continue work in EMP planning.

Identification of the Most Efficient and Least Cost Process for Conversion of Wellhead Gas to Transportable Liquid Products

Overview

Direct synthesis of methane to methanol is an example of a process that, once fully developed, could be a game changer for Bakken flaring reduction. This project investigated technology options for single-stage catalysis of methane or associated gas to liquid products. Many potential routes and end products were considered, but focus will be placed on the highest-value end products and simple processes that have shown promise in the laboratory.

Highlights

- While direct conversion of methane (DCM) has been actively studied for more than 50 years, few commercial successes have resulted because of methane's limited reactivity.

- Currently, four general approaches to converting methane are broadly recognized – all of which are challenged by wellsite conditions: 1) methane-utilizing microorganisms that have large equipment-space requirements; 2) complex chemical methods that mimic biological reactions; 3) other direct methods that require vigorous conditions, e.g., corrosive chemicals, and produce dilute product streams that require large equipment and purification requirements; and 4) indirect methods, e.g., steam reforming, that are complex and occur at high temperatures.

- Of all products produced by direct conversion technologies, methanol is likely the most appropriate for the Bakken when transportability, hazards, and market economics are considered.

- Of all technology providers available for teaming, McDermott is likely the most appropriate given its ethylene technology is in demonstration and McDermott has a nascent technology developed by a subsidiary (Siluria Technologies) that converts ethylene to motor fuels which McDermott might consider for joint development or demonstration with a partner that can provide funding.

- Ultimately, while an extraordinary number of combinations of DCM chemistries, catalysts and supports, processes, equipment, and products are available, there is an inadequate theoretical foundation to choose a path that would be suitable and successful for wellsite application in western North Dakota.

Next Steps

- Nothing at this time. Novel concepts related to this topic will continue to be considered.

Evaluation of Energy Storage Technologies and the Benefit to North Dakota Utilities

Overview

Energy storage is a key element in the modern energy supply process. Energy storage systems intake excess or wasted energy and store it until it is needed, at which time the stored energy is then released from the system and utilized. This project reviewed energy storage technologies, concepts, and current research. Select promising technologies were modeled to evaluate theoretical energy capacities and energy recovery efficiencies.

Highlights

- Twenty energy storage technologies were comparatively scored using multiple criteria (e.g., energy density, system life span, round-trip efficiency, response time) to assess their potential for commercial application for North Dakota entities.

- The three highest-scoring technologies were selected for further investigation: latent heat energy storage (LHES), thermochemical energy storage (TES), and liquid–air energy storage (LAES). Modeling was performed using ASPEN Plus software to ascertain the potential impact these three technologies would have if integrated into the electrical grid. The LAES process flow diagram is shown in Figure 6.

- Energy storage systems based on thermal energy (LHES and TES) offer significant challenges, both from the perspective of the ES system itself and from the large-scale perspective of operations and plant integration. Heat loss can play a significant role in the performance of TES systems.

- LAES systems are advantageous as a general form of energy storage, as they only require electricity for operation and eliminate the need to have a source of heat. However, LAES systems have low round-trip efficiencies. These systems also have high operation and maintenance costs for the cryogenic liquid storage system.

- Further research is needed on the LHES, TES, and LAES systems to improve the economic and commercial viability of these technologies.

Next Steps

- This project provided the information necessary to respond to multiple Requests for Information in preparation for federal funding opportunities.

- Two concept papers have been submitted in pursuit of a DOE funding opportunity. A proposal is being prepared for one of the concepts based on a positive response from DOE.

- Future funding opportunities will be pursued as applicable.

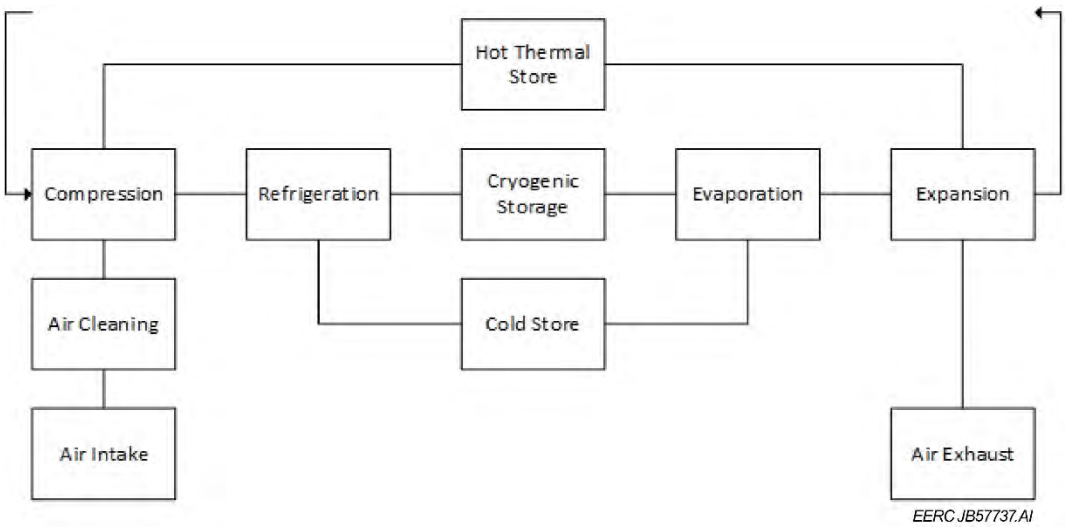

Figure 6. LAES system process flow diagram.

Solvent Extraction of Rare-Earth Elements from Lignite Coal In Situ

Overview

Previous work has shown that acid solvents can be effective at REE extraction from coals and coal ashes. The goal of this project was to evaluate whether in situ removal of REEs from lignite coal seams would be an effective way to produce REEs in an environmentally sound manner. A series of bench-scale tests using the EERC's subsurface extractive test system were conducted to generate subscale test data and assess conceptual process designs. REEs tested during this project included lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), scandium (Sc), and lutetium (Lu).

Highlights

- The literature identified how ISL (in situ leaching) has been used around the world, including China, which uses ISL for REE extraction from ores. Regulatory aspects governing ISL for the state of North Dakota were reviewed for their applicability to ISL extraction of REEs from coal.

- Coal samples for bench-scale testing were obtained from the Twin Butte coal seam at North American Coal Corporation's Freedom Mine and a core from the Hagel coal seam at BNI Coal's Center Mine. The EERC created a system to test plugs of coal and over/underburden to simulate the flow of solution through the coal in an ISL scenario.

- High-level economic analysis of a hypothetical ISL operation using recovery data from testing was conducted to show the economic potential of a coal ISL project in North Dakota.

- Testing showed that recovery of REEs from North Dakota coal ranged from 5% to 9% of available REEs in the coal, while other valuable metals such as Mn, Ni, Co, and Ge provided greater variation in extraction percentage (Figure 7). Variations in pH, strength, and type of acid used for extraction from the coal were identified as crucial aspects in designing an extraction process. Economically, metals other than the REEs provided the bulk of the value of extracted material. Of the REEs, Sc was recovered at the lowest percentage while having the greatest value.

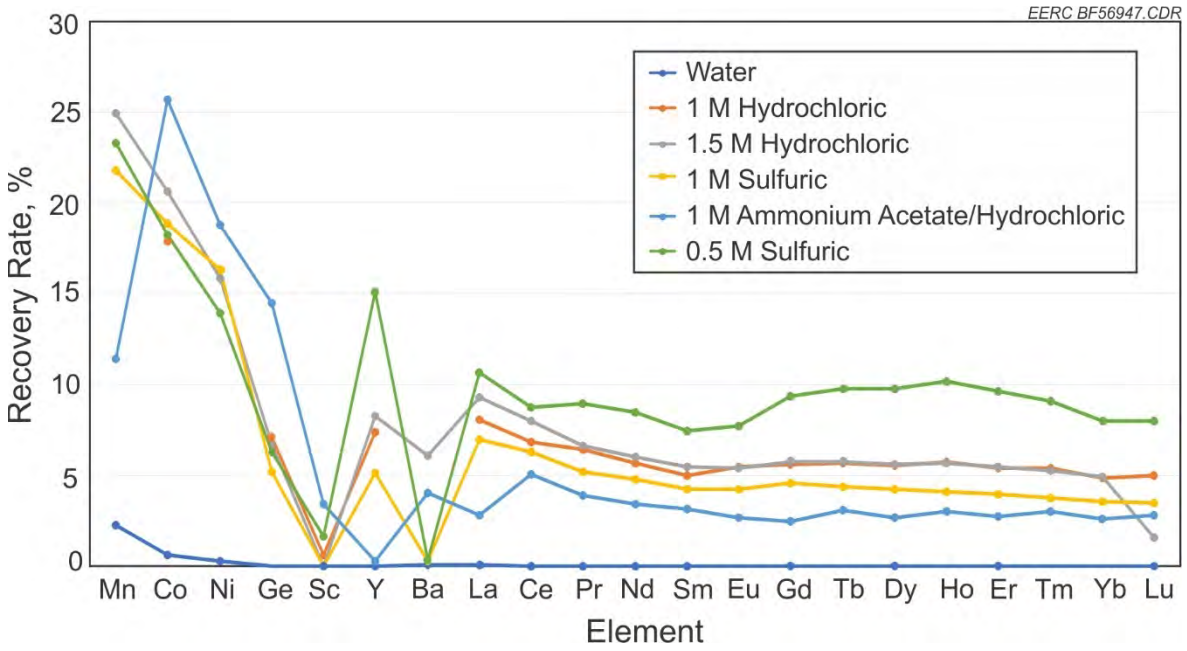

Figure 7. Recovery rates of REEs and other metals with varying acids and strengths, as well as alkaline solutions.

Next Steps

- Discussions regarding potential collaboration on funding opportunities have occurred with DOE's National Energy Technology Laboratory (NETL).

- A potential future scope of work has been considered that includes testing to maximize the recovery rate of REEs and high-value metals to enhance the economic potential of an ISL process. Various factors would be investigated, including the effect of fracturing on recovery, degradation of permeability over time, and efficiency of other solvents.

- Site-specific investigation into North Dakota coal seams that could serve as candidates for an ISL pilot test should also be performed. Conversations with a North Dakota mine about potential future pilot testing have occurred.

Enhancing Reservoir Productivity Through a New Hydraulic Fracturing Approach

Overview

Optimizing hydraulic fracture spacing by accounting for stress shadow development has the potential to increase stimulated reservoir volume and formation productivity in both the short and long term. This project focused on understanding the impact of stress shadows on hydraulic fracture effectiveness. An improved method to hydraulic fracturing design that considers the effect of reservoir properties and principal stresses (or stress shadow) was investigated.

Highlights

- The effect of formation properties and hydraulic fracture parameters on stress shadow development was simulated using XSite software (Figure 8). A method for optimizing hydraulic fracture spacing by considering the effect of stress shadow was developed.

- Findings show that formations with higher Young's modulus generally produce longer hydraulic fractures, whereas Poisson's ratio does not affect fracture length. Stress anisotropy influences the propagation direction of a hydraulic fracture but does not affect fracture length.

- Larger net pressures (i.e., the pressure contrast between shut-in fracture pressure and minimum horizontal stress) lead to larger stress shadow regimes. Fracture length and stress anisotropy play an important role in controlling the stress shadow regime.

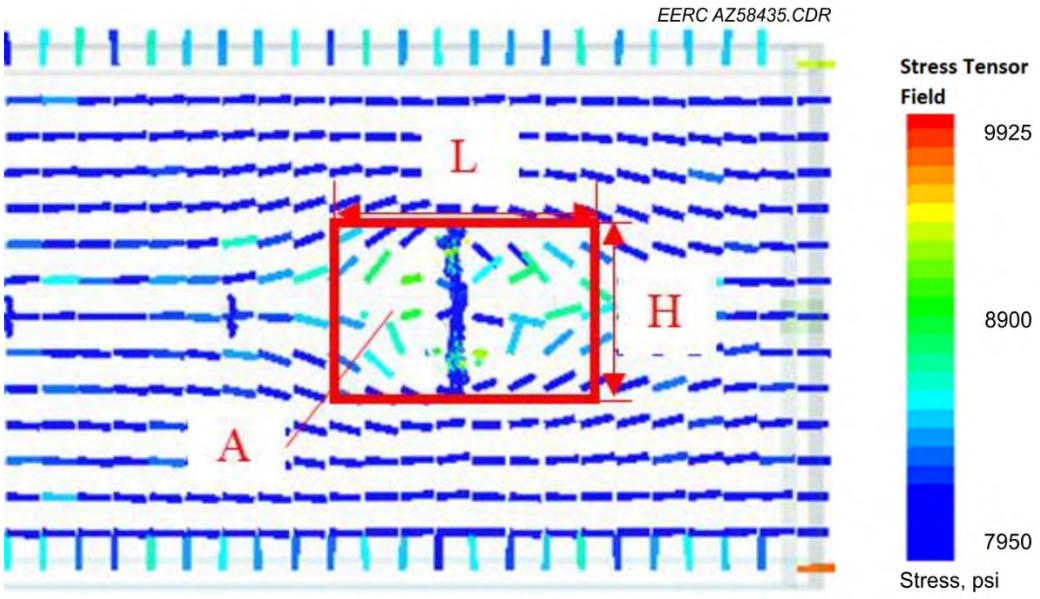

Figure 8. Schematic illustration of the stress shadow measurement: dashed lines show the magnitude and direction of minimum principal stress; the stress shadow regime is the red rectangle where minimum principal stress deviates from initial orientation; A, L, and H correspond to the area, length, and height of the stress shadow regime.

- Results indicate the optimum ratio of fracture spacing is 70% of the fracture length; i.e., the optimum fracture spacing is 210–245 ft for the Bakken Formation, where the fracture length is 300–350 ft.

Next Steps

- A Phase II scope of work has been envisioned to advance the concept of hydraulic fracture spacing optimization by performing laboratory experiments and hydraulic fracture model simulations using geomechanics and reservoir simulation software. This could identify the impact of fracture spacing on the total stimulated reservoir volume (SRV) and the production profile of a well, potentially improving the total recoverable hydrocarbon from each well. Federal or state funding opportunities will be pursued as appropriate for this follow-on work.

TASK 2 ANNUAL SUMMARY

Task 2 is intended to provide quick and efficient access to energy experts from the EERC for timely scientific and engineering studies to support the state's interests. Through this task, SERC has the ability to both react to, and proactively address, issues that have the potential to impact the state's energy and other (if appropriate) industries. All projects conducted through this task are at NDIC's discretion. At its March 24, 2020, meeting, NDIC approved a project under this task entitled "Assessing North Dakota's Energy Future." An overview of this project and its progress to date is provided below.

Assessing North Dakota's Energy Future

Overview

North Dakota's energy industries are constantly adjusting to meet the future environmental, social, and economic needs of its citizens. The state of North Dakota, while continuing an all-of-the-above energy approach, needs to be prepared for transitions in the energy industries that will affect issues such as 1) ensuring affordable, dispatchable energy is available for North Dakota citizens; 2) maintaining existing and expanding future employment opportunities; 3) maintaining North Dakota's healthy environment; and 4) maintaining state, tribal, and local tax revenues.

North Dakota is blessed with significant energy resources, including biomass, coal, petroleum, natural gas, wind, and more. Given the global COVID-19 pandemic and resulting shifts in demand, as well as overall market changes and societal pressure for low-carbon energy, maintaining North Dakota's ability to produce affordable and dispatchable energy from all of its resources into the future will depend on the ability to sustainably adapt. Sustainability includes economic, social, and environmental categories, each of which contain multiple factors that affect North Dakota.

The EERC initiated a multiphase research project focused on identifying the challenges and opportunities related to achieving energy sustainability for the state of North Dakota over the next 5 to 20 years. This effort will require a broad range of expertise, utilizing people with backgrounds

in economics, technology development, social sciences, policy, and the various energy sectors. Specific activities will include data gathering involving interviews and focus group meetings, data analysis, systems modeling, and report generation.

The EERC received approval from NDIC to use up to $500,000 from Task 2 of SERC to carry out Phase I of "Assessing North Dakota's Energy Future." The period of performance for this effort is April 1, 2020 – December 31, 2020, with the primary deliverable being an initial report identifying the challenges and opportunities facing North Dakota in achieving a sustainable energy future, including near-term action items for consideration. It is likely that additional effort beyond this project will be needed to pursue a fully comprehensive energy sustainability analysis.

Project Team

A multidisciplinary team of researchers are participating in this effort, including experts from the EERC, UND's Nistler College of Business and Public Administration, and North Dakota State University. Additionally, Ventana Systems has been engaged to help in the development of system dynamic models. To enhance the overall understanding of challenges and opportunities within North Dakota's energy industry, a series of expert panels and working sessions were conducted with North Dakota industry experts to enhance the efforts of the project team (see next section).

Industry Panels and Working Sessions

Four panel sessions were conducted to provided North Dakota industry representatives the opportunity to discuss the sustainability challenges and opportunities of their respective industry. Each panel session was then followed by a working session a few days later that provided an opportunity for the Ventana modeling team to present a first-generation conceptual model that would help in assessing the opportunities and challenges that were presented. The four panel and working sessions were focused on 1) coal, 2) oil and gas, 3) renewables, and 4) electrical transmission. These sessions were not intended to produce a comprehensive understanding of all facets of the energy industry, but rather an initial starting point for further research. Additional research by the project team was conducted to help fill in any industries that were not represented in these sessions.

Development of Relationships Between Critical Components

Within this project, one of the goals is identifying and quantifying relationships between the various components of North Dakota's energy industry and the concepts of maintaining and growing jobs and revenues, maintaining a healthy environment, and ensuring affordable and reliable access to energy. Figure 9 is a first-generation conceptual model showing the relationships between the various components considered in the study.

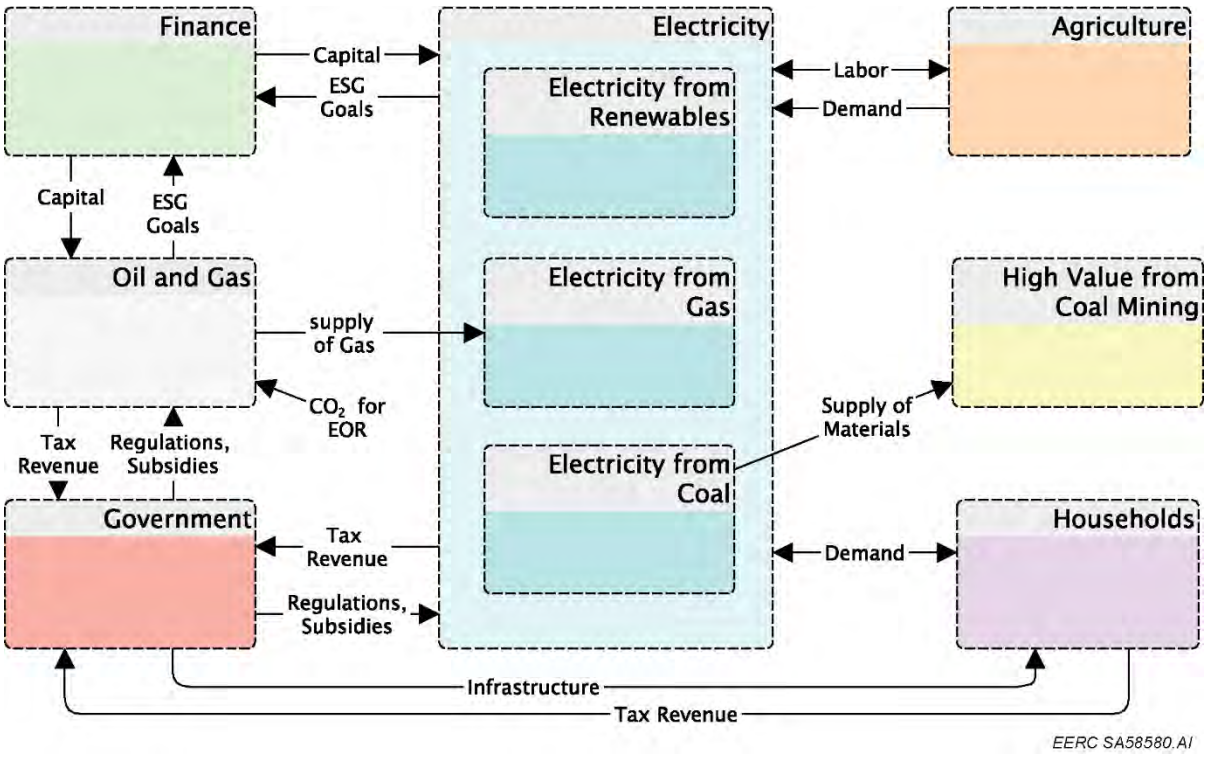

Figure 9. Identifying the critical relationships between North Dakota's energy sectors, the state, and citizens of North Dakota.

Future Work

This project will develop a series of small models that allow us to understand the relationships between the critical components of North Dakota's energy and other industries. These small models, along with other research activities and discussions with industry experts, state leaders, and other stakeholders, will be used to develop options to help ensure sustainability in accordance with the project's direction. This effort is considered Phase I of a much larger vision to develop a more comprehensive approach to ensuring sustainability.

TASK 3 ANNUAL SUMMARY

This task is focused on outreach activities to advocate for, and educate about, North Dakota's energy industries. Within this task, opportunities to collaborate with other North Dakota institutions of higher education were created. Two specific activities conducted within the first year were the Energy Hawks and the development of the E-Portal. Both are discussed below.

Energy Hawks – 2019

During the summer of 2019, nine students from UND were selected to participate in the Energy Hawks Program. The multidisciplinary Energy Hawks Program brings together students from a variety of academic programs to collaborate on identifying value-added opportunities for North Dakota energy. The nine students spent 10 weeks learning about all forms of North Dakota energy, including a weeklong tour of western North Dakota, visiting oil and gas, coal, ethanol, hydro, and wind sites, as well as a day in Williston, North Dakota to discuss impacts to the community and infrastructure with the growth of the oil and gas production from the Bakken petroleum system. The students used these experiences, as well as the opportunity to meet with energy experts throughout the program, to identify areas they believe can be improved or enhanced with further research. Three concept research projects were developed and presented by the students (Figure 10) and are summarized here.

Figure 10. 2019 Energy Hawks presenting their final concept papers.

Energy Hawks Concept 1: Artificial Photosynthesis: Fuel from CO_2 in North Dakota

Photosynthesis is a process whereby plants convert CO_2 with the energy of light to produce organic matter. This concept paper investigated applying CO_2 hydrogenation, also termed artificial photosynthesis (AP), on a large scale, colocated with a fossil fuel power plant. AP could be applied to the CO_2 capture stream at facilities such as that proposed for Minnkota Power Cooperative's

Project Tundra or for any other concentrated CO_2 source. Mimicking natural photosynthesis on a large scale to store and generate synthetic fuel will take advantage of excess electricity generation capacity in the state of North Dakota and can become an energy storage surrogate. This project investigated the opportunities and possible challenges of generating methanol as a synthetic liquid fuel, which is a relatively safe fuel with highly economical energy density.

Energy Hawks Concept 2: Harnessing Wind Energy Using Two-Way Vehicle Charging in North Dakota

Electric vehicle (EV) usage has increased recently as a result of improved technologies and lower prices. EVs reduce carbon dioxide and other emissions when used in lieu of gasoline vehicles, which is one of the most appealing factors of driving one. An additional benefit to driving an EV could be the potential to use the car's battery as electricity storage, thereby making EVs more appealing to consumers and giving the electric car more utility. This paper evaluated the concept, called bidirectional charging, to identify the challenges for such a system to be feasible in North Dakota.

Energy Hawks Concept 3: Social Media: Enhancing Energy Awareness among Young Adults

Digital natives aged 16–26 believe that renewable energy sources such as solar and wind are superior for electrical generation. In actuality, renewable energy sources are intermittently unreliable as sources for electrical generation when compared with fossil fuels or nuclear energy. To ensure reliability and the continuation of vital services, an all-of-the-above approach is necessary to provide affordable access to energy. This concept paper created a template to use future social marketing principles to create a public information campaign that 1) provides accurate information on electrical energy consumption and the technological innovations to make electrical generation cleaner, safer, and more reliable; 2) challenges digital natives to think critically about affordable electricity and how it relates to quality of life issues; and 3) spreads energy literacy to create a path toward productive participation in subsequent conversations as informed consumers. Focusing on digital natives as the target audience will channel digital native fervor for social engagement to encourage energy literacy.

Energy Hawks – 2020

The Energy Hawks Program for 2020 was initially planned to be conducted similar to 2019 with the addition of four students from other North Dakota institutions of higher education, including North Dakota State University, Bismarck State College, Williston State College, and Nueta Hidatsa Sahnish college. However, because of COVID-19, the summer internship program was moved entirely online. Because of a variety of circumstances, some institutions were not able to participate in this year's program. Participants from North Dakota State University and Bismarck State College (one from each institution) joined nine UND students in the 10-week summer program completed remotely (Figure 11). The disciplines of the selected students include engineering, physics, math, computer science, philosophy, and economics, with minors including political science, statistics, and biology. The program will be completed in early August with three concept papers prepared by the students, similar to previous Energy Hawk years.

Figure 11. 2020 Energy Hawks participating entirely remotely.

E-Portal

On July 31, 2019, a meeting was held at the EERC to discuss opportunities for collaboration across all institutions of higher education within the state of North Dakota. The invitation to participate went to all institutions across North Dakota and was not limited to those within the State Board of Higher Education. Additionally, visits were made to Lake Region State College and Mayville State College to solicit their involvement in this effort and discuss other potential opportunities.

Based on discussions during the July meeting, a web-based system allowing access to energy-related education and outreach information from the participating institutions was created. E-Portal is an online system that can serve as a one-stop shop for education and outreach information already existing within the different institutions. Figure 12 shows the concept of providing information and the participating institutions to date. The E-Portal system, www.ndportal.org, went live in June 2020. The information currently available within E-Portal is primarily from the EERC at this time with some information from Bismarck State College. Additional information from the other participating institutions will be added in the future.

Figure 12. Graphic showing an overview of the E-Portal concept and current participating institutions.

FUTURE WORK

The first year of SERC activities has resulted in:

- A significant increase in exploratory research.
- Research activities across all facets of North Dakota energy.
- A large increase in the number of new inventions.
- Initiation of the first phase of a statewide energy sustainability study.
- 20 North Dakota students participating in the Energy Hawks Program.
- Greater collaboration across the state's institutions of higher education.

The overall efforts of SERC will continue into the second year of the biennium, with significant work progressing on activities that have already commenced; however, no new projects are anticipated to be funded, as all $5 million available for the biennium was allocated within the first year. Although 25 new research projects were successfully funded, 59 innovative research concepts were brought forth by EERC researchers in the first year alone, with numerous additional ideas in discussion should additional funding become available. As appropriate, results will be presented to NDIC, the Energy Development and Transmission Committee, and the next North Dakota legislative body.

APPENDIX A

FINANCIAL SUMMARY

STATE ENERGY RESEARCH CENTER
Financial Summary as of June 30, 2020

Task	Budgeted	Allocated	Expended
1 – Exploratory Research	$3,750,000	$3,915,241	$1,846,558
2 – Prompt Expertise	$500,000	$460,000	$122,302
3 – Advocate & Educate	$750,000	$624,759	$299,015
Totals	$5,000,000	$5,000,000	$2,267,875

APPENDIX B

SENATE BILL 2249

Sixty-sixth Legislative Assembly of North Dakota
In Regular Session Commencing Thursday, January 3, 2019

SENATE BILL NO. 2249
(Senators Holmberg, Bekkedahl, Meyer)
(Representatives Mock, J. Nelson, Porter)

AN ACT to create and enact sections 15-11-40 and 57-51.1-07.9 of the North Dakota Century Code, relating to the state energy research center and the state energy research center fund; to provide a continuing appropriation; to provide a report; and to provide an expiration date.

BE IT ENACTED BY THE LEGISLATIVE ASSEMBLY OF NORTH DAKOTA:

SECTION 1. Section 15-11-40 of the North Dakota Century Code is created and enacted as follows:

15-11-40. State energy research center - Report.

1. The state energy research center at the university of North Dakota energy and environmental research center is created for the purpose of conducting exploratory, transformational, and innovative research that advances future energy opportunities and benefits the state's economy and environment through:

   a. Exploratory research of technologies and methodologies that facilitate the prudent development, and clean and efficient use, of the state's energy resources;

   b. Greater access to energy experts for timely scientific and engineering studies to support the state's interests; and

   c. Education and outreach related to the state's energy resources.

2. The state energy research center shall report all research activities and accomplishments annually to the interim legislative energy development and transmission committee and to the industrial commission. Upon request, the state energy research center shall report all research activities and accomplishments to the appropriations committees of the legislative assembly.

3. To effectuate the purposes of this section, the energy and environmental research center may:

   a. Select the research topics and projects to be pursued;

   b. Enter contracts or agreements with other North Dakota institutions of higher education to support select research topics and projects;

   c. Enter contracts or agreements with federal, private, and nonprofit organizations to carry out selected research topics and projects; and

   d. Accepting donations, grants, contributions, and gifts from any source to carry out the selected research topics and projects.

4. The state energy research center may not conduct research or pursue projects that will result in the exploration, storage, treatment, or disposal of high-level radioactive waste in North Dakota.

SECTION 2. Section 57-51.1-07.9 of the North Dakota Century Code is created and enacted as follows:

57-51.1-07.9. State energy research center fund - Continuing appropriation.

The state energy research center fund is a special fund in the state treasury. Before depositing oil and gas gross production tax and oil extraction tax revenues under section 57-51.1-07.5, one percent of the revenues must be deposited monthly into the state energy research center fund, up to five million dollars per biennium. All moneys deposited in the state energy research center fund and interest on all such moneys are appropriated on a continuing basis to the industrial commission for distribution to the state energy research center. The state energy research center shall use the funds in accordance with section 15-11-40.

SECTION 3. EXPIRATION DATE. This Act is effective through June 30, 2023, and after that date is ineffective.

President of the Senate	Speaker of the House
Secretary of the Senate	Chief Clerk of the House

This certifies that the within bill originated in the Senate of the Sixty-sixth Legislative Assembly of North Dakota and is known on the records of that body as Senate Bill No. 2249.

Senate Vote:	Yeas 47	Nays 0	Absent 0
House Vote:	Yeas 78	Nays 12	Absent 4

Secretary of the Senate

Received by the Governor at _____M. on _____, 2019.

Approved at _____M. on _____, 2019.

Governor

Filed in this office this _____day of _____, 2019,

at _____ o'clock _____M.

Secretary of State