February 15, 2018

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol – Fourteenth Floor
600 East Boulevard Avenue
Bismarck, ND 58505

Re: Proposal titled, "Conceptual Design for Chlor-Alkali and Valuable Materials Production from Oilfield Brine"

Dear Ms. Fine:

Barr Engineering Co. (Barr) is submitting a proposal for review under the Oil & Gas Research Program (OGRP). For the previous OGRP grant deadline of November 1, 2017, the University of North Dakota (UND) Institute for Energy Studies submitted a proposal that was related to that submitted herein. In the former proposal, UND was the main contractor, Barr was a subcontractor, and Triple 8, LLC provided a 50% match. Reviews of the former proposal were generally favorable but also requested more detail. The proposal was pulled in favor of resubmitting another one based on additional research. Our project has team decided that, going forward and if awarded, Barr will be the main contractor, UND will be the subcontractor, and Triple 8 will continue to provide the matching funds and in-kind support.

We propose to develop a conceptual design for a process plant with the following process goals:

1. Treat oil-field brines to generate high-purity sodium chloride brine and distilled water for use in a chlor-alkali process;

2. Manufacture caustic soda and hydrochloric acid to supply the regional market; and

3. Recover and concentrate high-value elements, such as lithium and rare earths, which are critical materials for modern electronics with rapidly growing markets and demand.

We are requesting $110,000 in support from the Oil & Gas Research Program of the North Dakota Industrial Commission. The requested support is being matched by Triple 8, LLC, the business that is interested in commercializing the proposed technology in North Dakota. Triple 8 is providing $75,000 in cash and in-kind support valued at $35,000. Barr will partner with the Institute for Energy Studies at UND.

If you have any questions or require additional information, please do not hesitate to contact either of us (Richard Hardegger, 952-832-2629, rhardegger@barr.com; Scott Korom, 701.221.5420, skorom@barr.com).

Sincerely,

Richard Hardegger, PE (Minn.)
Vice President, Project Principal

Scott F. Korom, PhD, PE
Project Manager

Enclosure: Application for Oil and Gas Research Program

February 15, 2018 Ref: L1917424384

BARR ENGINEERING CO
4300 MARKETPOINTE DR STE 200
MINNEAPOLIS MN 55435-5422

I, Myles S. Vosberg, Director of Tax Administration for the North Dakota Office of State Tax Commissioner, certify that the records in the North Dakota Office of State Tax Commissioner do not show any indebtedness owed to the State of North Dakota by BARR ENGINEERING CO, with respect to income taxes, sales and use taxes, or any other taxes collected by and payable to the Tax Commissioner's office. This company is, therefore, in good standing with the North Dakota Office of State Tax Commissioner. This certification does not include ad valorem property taxes collected by the respective county treasurers.

Dated this February 15, 2018 at Bismarck, North Dakota.

/s/Myles S. Vosberg
Myles S. Vosberg
Director, Tax Administration

Barr provided environmental permitting, constructability-study cost estimate, engineering design, and construction oversight services for this new crude oil refinery in Dickinson, North Dakota.

proposal application for

conceptual design for chlor-alkali and valuable materials production from oilfield brine

prepared for

Oil & Gas Research Program
North Dakota Industrial Commission

Submitted by Barr Engineering Co.
February 15, 2018

BARR

Oil and Gas Research Program

North Dakota

Industrial Commission

Application

Project Title: Conceptual Design for Chlor-alkali and Valuable Materials Production from Oilfield Brine

Applicant: Barr Engineering Co.

Principal Investigator: Dr. Scott F Korom

Date of Application: February 15, 2018

Amount of Request: $110,000

Total Amount of Proposed Project: $220,000

Duration of Project: 12 months

Point of Contact (POC): Richard Hardegger, Principal in Charge

POC Telephone: (952) 832-2629

POC E-Mail Address: rhardegger@barr.com

POC Address: 4300 MarketPointe Drive Suite 200, Minneapolis, MN 55435

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ABSTRACT

Objective

Approximately 1.3 million barrels of water are co-produced daily by oil and gas operations in the Williston Basin from the Bakken Formation in North Dakota, and due to its extreme level of total dissolved solids (TDS), the bulk of the water is pumped underground as a means of waste disposal. This underground disposal practice incurs significant cost to the well owner as well as risks associated with saltwater spills that have detrimental and long-lasting environmental effects. Although most of the dissolved solids content is simply sodium chloride, the brine also contains attractive levels of more valuable elements such as lithium, magnesium, bromine, and rubidium. These more valuable materials may not be economically recoverable by themselves, but prior work by researchers indicates that they are economically recoverable in conjunction with base commodity production.

Prior work also identified a local market of 1 million gallons per week of hydrochloric acid at a price of $1.35/gallon. The proposed project – Conceptual Design for Chlor-alkali and Valuable Materials Production from Oilfield Brine – will advance the ongoing work to develop the conceptual design for a process plant with the following process goals:

1) treat high-TDS wastewaters to generate high-purity sodium chloride brine and distilled water for use in a chlor-alkali process
2) manufacture caustic soda (NaOH) and hydrochloric acid (HCl) to supply the regional market
3) recover and concentrate high-value metals/elements in the waters such as lithium and rare earth elements, which have become critical materials for modern electronics/technology with rapidly growing markets and revenues

The conditions in North Dakota that make this process particularly attractive are overabundance of saturated brines and natural gas supplies from our oil production, excess electric generation capacity, above-average prices for base chemical commodities due to our distance from manufacturing facilities, and a manufacturing-friendly regulatory climate. The proposed project will improve the process economics further by locating it near the Lonesome Creek simple-cycle gas turbine plant to take advantage of free thermal energy from the gas turbine exhaust. Production of high-purity chemicals requires a source of distilled water. The process will employ commercially proven evaporation technology to produce the distilled water from the oilfield brine while making a high-purity sodium chloride salt feedstock for the chlor-alkali block.

The Lonesome Creek facility is a peaking plant, so it only operates when local electric demand and spot-market prices are high enough to require it. Consequently, the availability of free heat is inversely related to the availability of low priced electricity. This process will be configured to maximize the use of free heat when it is available, with the ability to minimize electric power consumption during those times when electric demands by other consumers are high. Unlike schemes to store off-peak electric energy, the proposed project concept employs a contrasting philosophy to match energy use to the source with the highest abundance at any point in time.

The largest challenges to overcome for commercializing chlor-alkali production from oilfield brines will be 1) economically segregating the sodium chloride from everything that could foul the membranes in the sodium cells and 2) supplying high-purity water to the process. Our conceptual design will employ standard distillation equipment, which will be tuned to precipitate sodium chloride selectively while producing distilled water. This process will use the exhaust heat from the Lonesome Creek gas turbines, which is available at essentially no cost. This source of "free" heat makes the purification of salt and water required for the process economically attractive.

Expected Results

This project will develop a preliminary base plant design, products list, and economic assessment for a near-term commercial facility that produces at least 1 million gallons per week of 35% hydrochloric acid solution along with a corresponding amount of caustic soda. The process will be designed in a modular way such that its capacity can be scaled up later to produce additional materials from brine. Module additions would be a future retrofit, if deemed economically beneficial. Finally, this project will also evaluate the feasibility of recovering other high-value materials, such as lithium, magnesium, rare earth elements, iodine, potassium, and bromine from the brines. Our approach to this project is to develop the platform for a low risk project that still provide an outsized economic return to the State of

North Dakota. The outcome will propose a vetted technology such that investment marketing and establishment of a commercial facility can commence relatively quickly.

Duration

The project duration is 12 months, with an estimated start date of April 1, 2018.

Total Project Cost

The total project cost is $220,000, with a request of $110,000 from the Oil & Gas Research Program. Triple 8 LLC is providing $75,000 in cash and $35,000 of in-kind support to the project.

Participants

Barr Engineering Co. (Barr) will be the lead organization for this project. The University of North Dakota Institute for Energy Studies (UND IES) and Triple 8 LLC will partner with Barr, the former will provide process modeling and laboratory analysis to support the process design, and the latter is the private business interested in commercializing the proposed technology, will provide matching funds and in-kind support. OneCor Services LLC supports our initiative and would like to take advantage of a local supply of HCl to increase its market share. Basin Electric Power Cooperative has previously supported development efforts on these concepts but was unable to process a support letter prior to this special RFP submission deadline. They are still considering supporting the project in the form of plant technical details as needed, and a letter could be submitted at a later date. Support is also being received through the extensive Williston Basin Water Chemistry Database of Isobrine Solutions, which is partnering with Triple 8 LLC to commercialize the proposed technology. We have also included a letter of support from Powers Energy Corp, who has not contributed funding but is active in the oil and gas industry and an enthusiastic promotor of industrial development.

PROJECT DESCRIPTION

Objectives

The overall goal of the proposed project is to develop the conceptual design for a chemical production facility that will:

1) produce bulk commodity chemicals that have high volume local markets;
2) concentrate high-value elements/minerals such as lithium with the potential to recover and purify them

Specific project objectives have been established as summarized below.

Based on the ongoing work at Barr and previous work at UND, incorporate the results gathered to date and:

1) produce the basis of design, which defines materials to be produced and their quantities, thermal and electric energy availability, and high-level process design parameters
2) prepare process flow diagrams (PFDs) and mass/energy balances
3) identify applicable environmental and site development requirements
4) identify waste disposal requirements along with TENORM quantification
5) update capital investment expectation

Perform laboratory testing at UND to:

1) test methods to progressively precipitate selected salts so they can be fractionated into several beneficiated streams
2) produce Aspen Plus® process models for heat and mass balance calculations

Statement of the Research Problem

Approximately 1.3 million barrels of wastewater per day are produced [1, 2] with oil and gas production in the state, most of which is injected into underground formations as a means of disposal. This is compared to about 1.1 million barrels of oil per day produced in August of 2017 [2]. Due to its very high total dissolved solids content (TDS), produced water is considered the largest waste stream associated with oil and gas production [3]. The ratio of water-to-oil production for a typical oil well increases significantly as the well ages, increasing cost of water disposal relative to oil revenue. The UND EERC projected more than a twofold increase in produced water volumes through 2035 as the Bakken formation continues to be developed [4].

Another significant challenge facing the industry is the need for large volumes of hydrochloric acid for acidizing wells and descaling. Hydrochloric acid used in the Bakken is shipped into our state at a considerable distance and cost. Market analyses conducted by Triple 8 indicate that about 1 million gallons per week are consumed at a local price of $1.35/gallon, representing $70 million per year. Large quantities of caustic soda are also consumed locally, which must be imported from out of state as well. The proposed project has the potential to co-produce caustic soda with hydrochloric acid at the above rate for a market value of $420 million per year.

Numerous other chemicals, not directly related to oil and gas production, are consumed in the state which must also be imported, including sodium hypochlorite for water purification, caustic soda for pH control and sulfur scrubbing, salt for de-icing, potash for fertilizer, and bromine for mercury capture at power plants. Other chemicals not presently used in the state in large amounts, such as lithium, chlorine gas, magnesium, rubidium, and hydrogen can be produced as well. These materials can be sold into the broader market or can be used to support development of a domestic chemical manufacturing industry. Any future development of a petro-chemicals industry in the region will be dependent upon a stable supply of base chemicals at a reasonable price; therefore, a chlor-alkali facility is a prerequisite for increased chemicals manufacturing.

Methodology

At the core of the proposed technology is utilization of large-scale waste heat sources that are available in proximity to the produced water sources along with electricity prices among the lowest in the world. The chlor-alkali process is very energy intensive, and although modern membrane technology has reduced the electric energy consumption considerably, electricity is still the single largest cost to production. North Dakota's abundant and low-cost electric power, along with a ready supply of brine, means that our cost of production should be considerably below the U.S. average.

Brine will be delivered to the site by truck with provisions for future delivery by pipeline. The brine will be pretreated to remove oil and sediments in a three phase separator. The brine will also be dosed with an oxidizer, such as sodium hypochlorite or chlorine, to convert hydrogen sulfide to sulfate for the health and safety of the employees and to prevent air pollution. Oil skimmed from the brine will be sold. Solids removed by the separator will be a mixture of sand and precipitated salt, which would make excellent road de-icer for winter application, but if a ready market cannot be found, it will be landfilled.

The brine will then enter the distillation and fractional crystallization process. The equipment will consist of a combination of multi-effect flash evaporators and falling film vapor-compression crystallizers (i.e., the plant will have two options for condensing the brine). Both of these processes are commercially proven and readily available. The multi-effect flash evaporators use a large quantity of low-grade heat, use very little electricity, and are comparatively low in capital cost. These will operate preferentially when the combustion turbines at Lonesome Creek are in operation and their exhaust heat is available. The vapor compression crystallizers do not require a source of heat; instead, they use large electric motors to compress the evaporated water and recycle the heat back into the system. However, they consume large amounts of electric power, so during periods of high-electric demand on the system, they will be shut down. Sufficient storage volume of both the purified salt and the distilled water will be provided to enable continuous operation of the chlor-alkali block.

Both types of distillation equipment are readily available and proven on high-TDS waters. Power plants which employ zero liquid discharge (ZLD) customarily use brine concentrators and crystallizers identical to those we intend to use. Two commercial manufacturers of this equipment are SUEZ and Veolia. Recently, Veolia designed and built a 60,000 bbl/day ZLD facility for Antero Resources in West Virginia to take produced water from Marcellus shale gas wells and make distilled water and solid salt. While ZLD has a different final objective than this project, it does prove the technical feasibility of the process.

The chlor-alkali block will consist of multiple membrane-type sodium cells as typical for modern installations. There may also be some bi-polar membrane electro-dialysis cells, depending on the comparative demand for either hydrochloric acid or chlorine and a market for hydrogen. These two methods of splitting sodium and chloride have differing requirements for electric power consumption, process heat, and capital investment so the optimal combination must be considered. In any case, the process design will allow for additional cells to be added of either type to adjust to changes in future market conditions. Figure 1 illustrates a basic block diagram of the system.

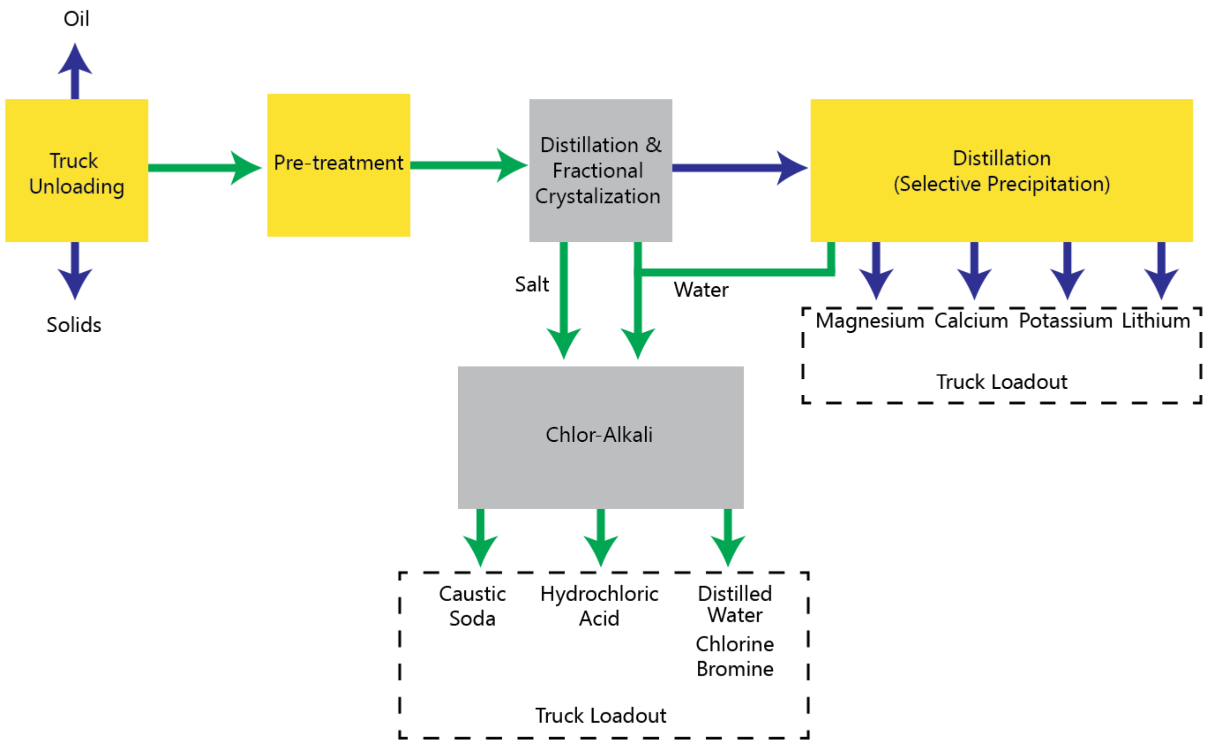

Figure 1. Block Flow Diagram of Proposed System

In this proposed configuration to produce distilled freshwater, NaOh, and HCl from high-TDS oilfield brines, the brine is first treated to remove oil, suspended solids, and hydrogen sulfide. Table 1 shows the brine composition results of the produced water analysis. Waste thermal energy available from a co-located gas-fired power plant is used to desalinate the brine into high-purity distilled water. High-purity sodium chloride is precipitated and sent to storage. The salt solution from storage undergoes electrolysis to produce bulk commodity chemicals with high-volume local markets.

Table 1. Produced water analysis from Three Forks Pool in the Williston Basin (UND – unpublished 2016)

		Anions			Cations							
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
pH	**TDS**	**Chloride**	**Bromide**	**Sulfate**	**Na**	**K**	**Ca**	**mg/L**	**Fe**	**Sr**	**Li**	**B**
6.08	289000	157000	470	65	88000	7480	10900	631	77	876	120	460

The pretreated brine, now containing a very high percentage of sodium chloride, is sent to the water purification and salt recovery block. Waste thermal energy available from a co-located gas-fired power plant is used to produce distilled water and crystallize the salts. A multiple-effect crystallizer can also be used to generate multiple precipitate fractions, an approach that is used by commercial-scale solar evaporation methods to generate a lithium-enriched salt fraction [5]. The precipitate fractions are sent either to the chlor-alkali process for use in the facility, or sent to dry storage for sale as ore enriched with lithium, rare earth metals, and other high value material.

The crystallized salts, containing approximately 98-99 wt% sodium chloride, are sent to the impurities-removal and chlor-alkali block. Impurities are removed via ion exchange and/or multiple recrystallization steps to achieve the typical specifications for sodium chloride brine feed to the electrolysis unit. Table 2 shows a breakdown of the typical specification for the process. We note that these are stringent requirements to meet the product purity specifications and to prevent membrane fouling in the electrolysis unit. Electrolysis occurs through the chlor-alkali process, a widely practiced commercial technology, which is summarized in Equation 1 and Figure 2. Electricity is applied to a system containing an ion exchange membrane. Cations (Na^+) are attracted to the cathode, and anions (Cl^-) are attracted to the anode. Liquid-phase sodium hydroxide (~35 wt% NaOH), chlorine, and hydrogen gas are produced. Subsequently, the chlorine and hydrogen can be condensed in water to form concentrated hydrochloric acid. Alternately, the chlorine gas can be compressed, liquefied, and sold, and the hydrogen gas can be compressed for sale or used as combustion fuel to recycle power and/or thermal energy to the process.

Table 2. Typical NaCl feed specification for chlor-alkali process

sodium chloride	280 - 305	g/L
calcium and magnesium	0.01	mg/L
silicon dioxide	5	mg/L
sodium sulfate	7	mg/L
aluminum	0.05	mg/L
iron	0.5	mg/L
mercury	0.04	mg/L
heavy metals	0.05	mg/L
fluoride	1	mg/L
iodine	0.4	mg/L
barium	0.4	mg/L
strontium	0.5	mg/L
total organic carbon	1	mg/L
pH	2 - 11	

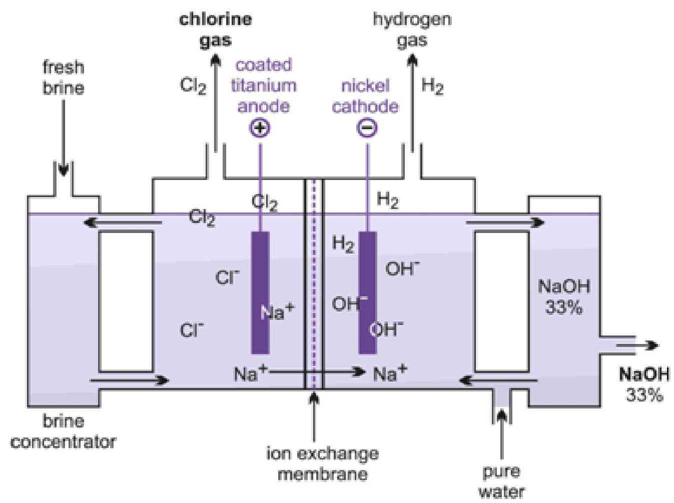

Figure 2. Schematic of the membrane cell chlor-alkali process

Equation 1. $2NaCl + 2H_2O + \text{electricity} \rightarrow 2NaOH + Cl_2 + H_2$

The bipolar membrane electro-dialysis is a similar process to the membrane cell except that when the sodium chloride is split, a water molecule splits into H^+ and OH^- ions to balance the reaction and prevent hydrogen gas and chlorine gas from liberating. This results in a significantly lower consumption of electricity; however, production of acid and caustic is limited to about 4% concentration, so the product must then be concentrated further by evaporation. Whereas the membrane cell produces concentrated caustic soda and chlorine gas with a large amount of electricity and no thermal energy requirement, the electro-dialysis method uses a small amount of electricity and large amount of heat to produce hydrochloric acid and caustic soda. Incorporating both methods into the facility gives it the ability to adjust in real time to changes in thermal energy availability and electric pricing.

In addition to production of distilled fresh water and commodity chemicals, provisions will be designed for the future recovery of lithium, magnesium, bromine, and other valuable materials. The solution stream, which leaves the salt and water purification block, has been depleted of sodium chloride and water, so its volume has been reduced; consequently, the concentrations of all other constituents have been increased making recovery of those materials easier and less costly. The project will not attempt to recover those materials at this time; they will be delivered as “ore” to other entities specializing in recovery and production of such commodities. We expect that in the future local or regional companies will enter the business of recovering and purifying these specialty products when a source of raw materials is readily available.

Project Scope of Work

To achieve the overall project objectives, the project scope of work has been divided into the following series of tasks.

Task 1: Market Analysis – Triple 8 will continue its market research to identify and quantify the regional demand and pricing for hydrochloric acid and caustic soda. We will concentrate first on supplying the regions that are accessible by truck delivery. The second consideration will be rail delivery to the extent that we have excess product or the pricing is attractive. The production from this project will be an insignificant fraction of the overall U.S. consumption, so rail deliveries represent essentially an unlimited market.

Task 2: Basis of Design – Using the work completed to date, we will develop the basis of design for the facility. This will define the site-specific conditions, design codes and standards, production rates for the specified commodities, quality specifications for materials produced, and other high-level parameters that will be required during the detailed design phase.

Task 3: Conceptual Design of Facility – The conceptual design will include the high-level process flow diagram (PFD), preliminary piping and instrumentation diagrams (P&IDs) for core systems, equipment list with preliminary sizing, site layout, and estimate of waste streams (solid, liquid, gaseous).

Task 4: Process modelling and selective precipitation tuning – To support the proposed project, the UND IES will provide:

1) Laboratory testing of methods to purify the oilfield brine. The testing will involve methods to separate divalent cations as well as fractional crystallization tests. This testing will be based on the approaches currently used for commercial lithium production using solar evaporation ponds. We expect that, by using a fractional-crystallization approach that takes advantage of relatively solubility differences of the various cations in the brine, we can generate salt fractions that are enriched in sodium chloride and lithium and potentially other valuable elements/minerals. The sodium-chloride-enriched salt fraction can more effectively be used as the feed for the chlor-alkali process, as it will require less purification prior to use. The salt fractions generated will also be analyzed to determine the partitioning of other potentially valuable elements/minerals, such as magnesium, bromine, and iodine. IES will work with the Barr team to identify the potentially salable elements/minerals in the brine.
2) To support the Barr's plant design, the IES will provide Aspen Plus® process modeling to help determine material and energy balances and size process equipment. IES will work directly with Barr to assist in generation of process flow and piping and instrumentation diagrams. The IES will also support Barr with estimation of the process economics.
3) The IES will prepare reports and required deliverables as dictated by the Research Agreement between UND and Barr and support the project reporting requirements of the Research Agreement between Barr and the NDIC.

Task 5: Consideration of environmental requirements – Based on information from the basis of design and the conceptual design, a review of applicable regulations will be performed to determine the permits required to construct and operate the project. These regulations may apply to air emissions, waste water discharge, solid waste management, hazardous waste storage and disposal, industrial stormwater management, naturally occurring radioactive materials (NORM) management, and overall monitoring and reporting. This facility is expected to have a relatively small environmental impact; however, that assumption needs to quantified and documented.

Task 6: Update of capital cost expectation – Our work to date has identified an approximate capital investment of $300 million for chlor-alkali facilities of similar capacity. Since this facility will have some different features, we expect the required capital investment to vary somewhat. We will use the approach of estimating adders and deducts to compare with a typical new chlor-alkali plant to produce an order-of-magnitude range of pricing.

Clarifications and assumptions:

- The budget does not include time or travel expenses for out-of-town meetings.
- It is expected that any liquid waste from an operating facility can be disposed in a Class 2 SWD. No consideration is given to permitting new wells or discussing with NDIC about the disposition of oilfield waste water from which materials have been removed.
- Conceptual design will not account for site-specific conditions such as soils, geotech conditions, wetlands, etc.
- The capital cost expectation will provide an order of magnitude range with +50 / -30% precision.

Anticipated Results:

The final deliverable will be a complete report containing the information described in the Project Scope of Work above.

As described previously, our approach to this project is to build upon the work done to date by Barr and UND, to de-risk the project, and to move it closer to an investable condition. Upon completion of this work we estimate that approximately 1% of engineering will be done. This will be sufficient for the project to proceed to a detailed feasibility study and for discussing with potential investors.

Overall, we have structured our technical approach to provide a low-risk development investment that has potential for a large impact leading to a new industry for North Dakota. This approach combines the strengths of in-state commercial and academic professionals with the natural resources which are abundant in the state. Our anticipated results of these efforts are to:

1) demonstrate the financial feasibility of producing base chemicals from a readily available feedstock
2) define the parameters for supplying locally manufactured chemicals to the state's energy industry for improved profitability and reduced dependence on out-of-state suppliers
3) provide a framework to increase production rates of these chemicals and to expand production into other valuable products
4) de-risk the proposed technology to a point where we can realistically attract commercial investment

Facilities and Resources

Barr provides engineering and environmental consulting services to clients across the Midwest, throughout the Americas, and around the world. Barr has been employee-owned since 1966 and traces its origins to the early 1900s. Working together, nearly 750 engineers, scientists, and technical support specialists help clients develop, manage, and restore natural resources. Barr's project teams work with clients in industries such as power, refining, mining, and manufacturing, as well as with attorneys, government agencies, natural-resource-management organizations, and others with complex problems.

In 2002, Barr partnered with Great River Energy (GRE) and the U.S. Department of Energy to develop the next notable improvement in coal-based energy production. This became the Coal Drying project at GRE's Coal Creek Station, which is now well known in the industry. Over the course of the project, Barr provided process development, evaluation, and selection; contributed to technology development; selected equipment; and designed the pilot-test unit (which processed two tons of coal per hour) and the prototype unit (75 tons per hour). Barr played a central role in GRE winning an $11 million DOE grant for the project by providing preliminary designs and cost estimates and assisting with the grant application. Barr was an integral part of the completion of the commercial unit. Barr completed detailed designs for the commercial unit, which processes 1,000 tons of coal per hour; designed a new crushing building as well as new elevated conveyors, galleries, and bents to supply coal to the dryers; and provided construction observation services during the two-year construction period including field engineering. The new coal-drying technology is being marketing globally by GRE for successfully reducing emissions and cost of energy production.

UND has exceptional laboratory and analytical facilities that will be leveraged in the proposed project. Equipment procured/constructed as part of previous projects on extractive metallurgy and adsorbent-based processes will be leveraged in this project. The UND Materials Characterization Laboratory (MCL), located at the College of Engineering & Mines, has several analytical instruments that will be used in this work, including X-ray diffraction, scanning electron microscopy, thermal gravimetric analyzers with differential scanning calorimetry, and X-ray fluorescence, as well as several small furnaces of various types. The UND Chemistry Department has the necessary instruments to perform the water chemistry analysis proposed in Task 2, and can include measurement of minor and trace species as well using its inductively coupled plasma-mass spectrometry instrument. UND and Barr both hold licenses and have personnel experienced in the use of process modeling software Aspen Plus® and ChemCAD. These programs will be used to assist with the design of plants to be evaluated in Task 1 of the project. In addition to the facilities required for the proposed work, UND has the facilities and personnel expertise to host and lead subsequent larger demonstrations.

Techniques to Be Used, Availability, and Capability

As described previously, this project combines plant design and experimental laboratory testing efforts. The techniques to be used have been described in the Project Scope of Work outlined previously in this document and in the Facilities and Resources section above. The design portion of the scope will be performed by Barr, based on expertise in the design and engineering of industrial facilities. Resumes for key individuals are included in Appendix C. The experimental testing will be done by UND; availability will not be an issue for any of the proposed equipment or analytical instruments. The UND MCL is staffed by full-time analytical chemists and is available for any UND research or educational need. The equipment to be used is currently housed at the UND IES and will be fully dedicated to this project. As well, the capability of each of the chosen techniques is well suited to the proposed scope of work and will provide us with the necessary technical information to be able to effectively evaluate and optimize the processes to be tested.

Environmental and Economic Impacts while Project is Underway

There will be little to no environmental impact during the proposed project. The project team will follow all UND regulations relating to hazardous waste disposal and will verify that any testing effluents are properly cleaned prior to disposal. The economic impact of this project will be in providing employment opportunities for UND/Barr staff and UND students. Additionally, this project will provide educational opportunity for both graduate and undergraduate students and will train them with hands-on engineering, ultimately improving the technical competence of the North Dakota labor force.

Ultimate Technological and Economic Impacts: The major technical impacts of the proposed project are to establish the design of a base plant to purify high-TDS oilfield wastewaters into high-purity distilled water and salt to manufacture base commodities with high volume local markets. While many others have investigated in high-TDS brine treatment methods, none have found wide adoption in the Williston Basin. This project will perform the needed steps to de-risk the proposed technology sufficiently to attract near-term commercial investment. This project will adapt commercial ZLD equipment for the selective precipitation of high-TDS brines into purified salt for feedstock to a commercial chlor-alkali process. Additionally, this project will incorporate design provisions for valuable materials recovery as a future retrofit to the existing base plant described above. This integrated approach can provide significant economic impacts in a low-risk project, as summarized below:

1) 35% hydrochloric acid will be produced, which has an immediate market size of 1 million gallons per week and a price of $1.35 per gallon.

2) The corresponding quantity of caustic soda will be produced which can be sold locally or delivered by rail into the US market at attractive pricing. Our prior work indicates that our cost of production will be 10% - 50% lower than other US producers.

3) High-purity distilled fresh water will be produced that can be used not only in hydraulic fracturing, but also in the more stringently demanding applications such as well maintenance, agriculture, and potable drinking water markets. Well maintenance has been identified by the UND EERC [4] as a quickly growing application, and our very low-TDS fresh water will be especially suited to this application as it can alleviate water quality/compatibility concerns facing the industry.

4) The bulk commodity chemicals produced locally will improve profitability of local industry. By eliminating the high transportation costs (up to about 10% of the wholesale product cost) assessed to the consumers of these chemicals, we expect to be able to provide benefit to these local markets. The plant can also be a geographic hub for the northern/western portion of North America.

5) The chlor-alkali process that will be investigated to produce the above commodity chemicals is an electric-energy-intensive process, and most existing facilities are located in regions with high electricity costs. North Dakota's electricity costs are among the lowest in the nation, providing another advantage. A large consumer of electricity in the state will help convert our low-price electricity into high-value chemicals with significant benefit to our power industry. Co-location of the chemicals plant with an existing power plant can also provide some cost-saving synergies. In the case of a peaking plant, such as Lonesome Creek, the process may provide added incentive to operate the power plant at higher capacity than it otherwise would.

6) Lithium has been identified as a critical material for developing applications such as hybrid/electric vehicles and solar cells. Lithium-ion battery markets have been flourishing in recent years, resulting in a corresponding increase

in lithium carbonate prices. The proposed work will establish a low-cost source of lithium concentrate or high-purity lithium carbonate that can help satisfy this market;

7) Rare earth elements (REE) have been identified by the U.S. DOE [7] and others as crucial materials in an incredible array of consumer goods, energy systems, and military defense systems. Highly mineralized brines, such as those in the Williston Basin have been identified as one of the promising sources of these elements [1]. This project will leverage expertise at UND in extractive metallurgy and refining of REE to evaluate the feasibility of their recovery from high-TDS oilfield brine.

8) The produced water from Bakken Formation wells has attractive levels of bromine. Bromine is an important component of fire-retardant materials and, at present, is produced at high cost from dedicated wells. In conjunction with our existing process, we can co-extract bromine at minimal cost.

9) Magnesium is present in attractive amounts and can be readily precipitated by the process we will employ. Production of metallic magnesium requires large amounts of electricity. At present, about 60% of magnesium is produced from sea water in California where electric costs are several times higher than North Dakota.

10) The proposed project has potential to lead to multiple, completely new industries for North Dakota and provide benefits associated with job creation and tax revenue.

11) In addition to the technical/economic impacts, the proposed technology will result in a significant decrease in the environmental impact of the highly distributed handling / disposal of produced waters, which has resulted in numerous, highly publicized brine spills and is consuming the capacity of the Dakota aquifer. Centralizing a large portion of the produced water distribution will result in fewer spills and reduce deep well injection practices. Also, by transforming the largest waste stream associated with the state's oil and gas production into valuable products, the public perception of the industry will be improved.

Why the Project is Needed

As described in the Project Objectives section, water is one of the biggest challenges currently facing the oil and gas industry in North Dakota from both fresh water acquisition and wastewater disposal standpoints. While there has been a tremendous amount of work performed by others looking at ways to treat high-TDS wastewater, none have yet garnered wide commercial deployment in the Williston Basin for primarily economic reasons. The proposed project will solve the economic hurdles and make large-scale treatment and recycling of high-TDS oilfield wastewaters economically viable. Synergistic chemicals production is also possible with the proposed technology. For example, hydrochloric acid and sodium hydroxide are bulk commodity products that have high-volume local markets in North Dakota's oil and gas industry. *By producing these chemicals cost competitively in the state, we can eliminate high transportation costs currently being assessed on the users of these chemicals*. Additionally, this project will be designed to allow for adding processes and equipment for removal of other valuable materials which are known to have very high concentrations in certain locations and formations in the Williston Basin.

Lithium

The lithium market is currently undergoing a boom due to increased production and demand for lithium-ion batteries. Lithium is currently used in a number of applications, but the major driver for the industry is the projected growth in the battery industry from increased demand for lithium-ion batteries for applications such as hybrid/electric vehicles. Pike Research projected the automotive lithium-ion battery market to grow to $22 billion by 2020, up from about $1.2 billion in 2012. Figure 3 illustrates Wealth Daily's projection for lithium demand to grow about ten-fold by mid-century, and with demand moving steadily ahead of current global production rates, it is clear than new production must be brought online

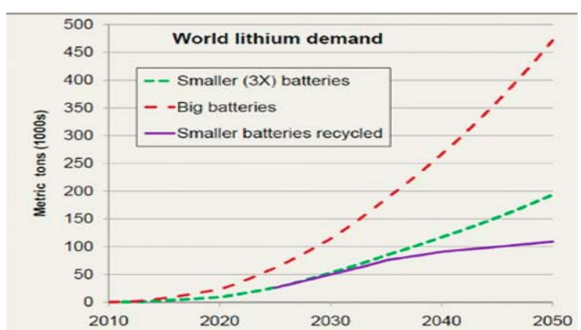

Figure 3. Lithium demand projections for lithium-ion battery market [29]

to satisfy the fast-growing market. Based on the above, we feel that this market for our proposed technology is readily available and desperately seeking new sources of lithium.

Magnesium

In 2017, approximately 620,000 metric tons of magnesium were used in the United States [7], only about half of which was produced in the United States. Magnesium metal is used as an alloying element in aluminum to make strong, lightweight, corrosion-resistant alloys. The use of magnesium/aluminum alloys in automobiles has been rising steadily and is expected to continue to rise because of demand for more fuel-efficient vehicles. Magnesium is also used in lightweight batteries and compares favorably with lithium-ion cells in energy storage density.

About 70% of the magnesium produced in the U.S. is from seawater and natural brines in California, Delaware, and Michigan primarily with some production in Utah (reference to USGS paper). Production of metallic magnesium requires a large quantity of electric power, and all of those states have electric power prices higher than North Dakota. The electrolytic process for producing magnesium requires about 35 MWh per ton of metal. In North Dakota, that quantity of electricity would have a cost of $475, and in California that would cost $1,160. The nearest price competitor to North Dakota for production of magnesium metal is Utah, where it would cost $620; therefore, production of metallic magnesium has a clear cost advantage in North Dakota. Additionally, the processes required for separation and purification of the magnesium chloride solution are already part of the plant design, as are the collection and sale of the chlorine, which is a byproduct of magnesium electrolysis. The market value of the magnesium that we can produce with this facility is estimated at $4.6 million per year.

Bromine

In 2017, approximately 23 million metric tons of bromine were used in the U.S [8]. Bromine is used for brominated fire retardants, drilling fluids, water treatment, and mercury capture in power plants. It is also widely used as an intermediate in the production of other chemicals. Most of the bromine produced in the U.S. is from underground brines in Arkansas. Bromine prices during 2017 were around $5000 per ton, making the value of the bromine we can produce from the proposed facility close to $13 million per year. Bromine production will be a byproduct of the hydrochloric acid manufacture essentially, so collection and sale of it will represent an operation with a very high margin.

STANDARDS OF SUCCESS

The proposed project directly addresses the mission of the Oil & Gas Research Program and has the potential to be a significant new industry for the state. We are targeting treatment and value-added use of the largest waste product currently associated with the state's oil and gas production employing the state's abundant low-cost electricity supply. We will also develop and design methods to take that waste material and generate commodity chemicals that have large volume local markets. Local production of these commodities will reduce costs of transportation to North Dakota and will reduce costs of the operations that use them. Sales of these chemicals and commodities into the larger US market will bring additional revenue into the state. The results of this project will advance the commercialization efforts of Triple 8 LLC and its partners and will de-risk the technology to a point where investment marketing can be initiated. The standards of success for this effort will be the delivery of a design package of sufficient detail to take into a detailed feasibility study. The design package will represent about 1% of the engineering necessary for construction of a commercial facility. This will be sufficient to adequately define the project to potential investors for progression to the next phases of project development.

Multiple companies in the region have expressed interest in either purchasing product from a facility such as this, or investing in this project. Successful delivery of the design package will give confidence to the interested parties that the proposed facility has merit.

BACKGROUND/QUALIFICATIONS

Summary of Current Approaches to Supply Hydrochloric Acid and Caustic Soda

At present, there is no production in North Dakota of hydrochloric acid or caustic soda. All consumption of these base chemicals must be supplied by out-of-state producers. Caustic soda is produced along with chlorine gas in chlor-alkali plants scattered throughout the continental US. Because salt is the basic feedstock, most of these are located near large salt deposits in places like Ohio, Michigan, and Texas, or near the ocean such as the Gulf Coast. Hydrochloric acid is made from the chlorine produced at the chlor-alkali plant by burning it with hydrogen and dissolving into water. There are small local chlor-alkali plants which manufacture for specific facilities in places like Iowa and Minnesota, but most caustic and hydrochloric used in North Dakota must be transported in from the large suppliers in Ohio and the Gulf Coast. Consequently, transportation costs can be as much as 30% of the delivered price. Transportation to the region is by rail to a terminal equipped with facilities for receiving, storing and transloading these chemicals. From these facilities, the chemicals will be diluted and delivered by truck to the end user.

Summary of Current Approaches for Wastewater Disposal and Treatment

Currently, the main method for disposal of produced and frack-flowback water is deep-well injection. With this method, the wastewater is transported to the injection site via pipeline or truck and is then pumped underground into depleted oil formations or deep saline reservoirs. In August 2015, there were over 400 injection wells operating in North Dakota, with about a quarter of these installed since 2008 [10]. There are several potential challenges and environmental concerns associated with deep-well injection. One of these is depletion of storage capacity over time. In its recent report, the UND EERC [4] suggested that the continued industry reliance on the Dakota aquifer as a disposal target requires a careful assessment to determine the long-term impacts of water injection, and evaluation of the capacity of alternative aquifer targets. The UND EERC report also estimates that as many as 1,500 new disposal wells may be needed by 2035 to account for the growth in produced water generation volumes.

Another major challenge with deep-well injection is that highly distributed handling and transportation has potential to lead to spills. Lauer and others (2016) [11] compiled information on brine spills in North Dakota since 2007 and have identified about 3,900 reported spills. In their studies, the authors also evaluated surface-water quality as a result of spills and found elevated levels of dissolved salts and other contaminants, as compared to background water. They concluded that the contamination was remarkably persistent, with elevated levels of contaminants observed for up to four years after spill events. Lastly, although not reported in North Dakota, earthquakes in the central part of the United States have been linked to oilfield wastewater injection practices. The water puts pressure on underground fault lines, causing induced earthquakes. It can also push up on the ground surface, a process known as uplifting. Oklahoma has seen a massive increase in earthquakes magnitude 3.0 or larger – more than 900 in 2015 alone – which have been linked to injection of oilfield wastewaters [12].

There are some methods for treatment and recycling of high-TDS wastewaters, but as of yet, none are widely deployed in North Dakota. For instance, in 2013 Halliburton came out with a wastewater treatment process specifically for the Bakken play, which was tested at pilot scale with Statoil in the spring of 2014 [13]. Despite the technical success of the pilot test, as of April 2015, none of the Bakken producers had adopted the technology due to economic reasons [10]. The UND EERC [14] has also conducted a review of technologies for treatment and recycling of oilfield wastewaters. Its review indicated that treatment will require extremely robust technologies built on mobile platforms and concluded that the most applicable technologies are based on thermal or membrane processes. Thermal treatment uses heat energy to evaporate moisture into steam, which can be followed by condensation of the steam to produce clean water. Thermal methods can be used as a brine concentrating step or for complete evaporation and recovery of crystallized solids. Antero Resources has a facility using thermal processes to produce distilled water and dry salt. This facility was built at a cost of about $300 million and is supplied by dedicated natural gas wells for evaporating the water. Thermal methods require prohibitively large energy input and, under most circumstances, are not considered economically feasible. However, EERC concludes that use of waste heat sources may make thermal treatment a viable option.

Thermal treatment processes evaluated in the EERC study included methods based on counter-current evaporation/condensation and mechanical vapor recompression (MVR), both of which are methods that recycle energy within the process, lowering overall energy demands. MVR, for instance uses the energy of the evaporated water, after a small steam compression step, to recycle back to the process, and depending on the number of stages, can significantly reduce energy requirements. A tradeoff is the complexity and capital expense of multi-stage systems. However, multi-stage evaporators can be used to fractionally precipitate the mixed salts in the brine and potentially create concentrated or high-purity mineral salts that could be salable. The current dominant method for commercial lithium production uses a similar approach, with fractional (staged) precipitation of the mixed salts in the brine into more concentrated fractions.

A second set of treatment methods is based on membrane technology, including reverse osmosis (RO), electrodialysis (ED), and nanofiltration (NF). RO is a process by which semi-permeable membranes take advantage of dynamic pressure to overcome osmotic pressure of saltwater, producing a low-TDS product and high-TDS concentrate. ED involves selective movement of ions through a membrane in response to electric current with energy consumption proportional to total salts removed. NF is a process that removes specific types of salt ions (i.e., Ca, Mg, and sulfate), but not others (Na, Cl). Overall, membrane processes suffer from high capital costs, large energy consumption, and complexity due to requirements for multiple treating steps to achieve necessary TDS removal rates. Their applicability to oilfield brine is questionable due to these reasons and the extreme TDS levels in the wastewater. It is also unclear if producing a dry solid product that could be sold to market or used for chemicals/minerals production is feasible.

Overall, the EERC study indicated that thermal treatment processes were most likely to be feasible for North Dakota. However, they also concluded that although there are likely to be niche opportunities for wastewater treatment, widespread deployment is not likely to be economically viable given existing technology.

Summary of Current Competitive Landscape for Recovery of Lithium from Oilfield Produced Water

There is a tremendous amount of literature discussing early stage research on recovery of lithium from saline water such as oilfield produced water. Our review of this literature has resulted in our choice of two of the most promising options, both technically and in terms of time to commercial readiness, for evaluation on Williston Basin brines in this project. However, there also appears to be one nearer-term competing technology offered by MGX Minerals [15]. MGX has been buying up mineral rights mainly in Alberta, Canada, but also in some locations in Utah and are developing a process for recovery and purification of lithium and other elements/minerals in oilfield wastewaters. In August 2017, MGX initiated pilot-scale testing of its technology and are anticipating completion of its first commercial lithium recovery unit (120 m3/day water feed) in November 2017. Very few details are available regarding its technology (provisional patent filed), but MGX claims significant improvements over traditional solar evaporation methods. However, their technology is built on small, modular platforms with relatively low throughputs. Our proposed plant can process about 50,000 barrels per day (bbl/day) (for the Basin Electric Lonesome Creek Station near Watford City, ND), while MGX's first commercial unit is being sized for about 750 bbl/day. This gives our proposed plant a tremendous economy-of-scale advantage as well as the advantage of having a centralized water collection and distribution point to reduce transport costs.

Summary of Previous Concept Development by the Project Team

The proposed concepts for treatment of high-TDS oilfield wastewater into high-purity distilled water, bulk commodity chemicals, and high-value metals/elements have been developed in a collaborative effort between UND IES, Triple 8 LLC (project co-sponsor and commercialization partner), and Barr. Triple 8 LLC became interested in this business concept after learning of the potential to recover lithium from a currently wasted product, as well as the booming market for lithium carbonate for lithium-ion batteries. Triple 8 approached the UND team to help develop technical details for a process to recover the lithium. Based on this initial exchange, the UND team enlisted the help of a UND chemical engineering senior design group to develop plant designs and evaluate the economic feasibility of potential options. This effort was supervised by Dr. Daniel Laudal.

Based on our experience in the electric utility industry, we are aware of the tremendous amount of available waste thermal energy available at power plants. After speaking with Basin Electric and getting its support for this initial effort, we decided to investigate the use of the hot flue gas (~900°F) exiting the simple cycle gas turbines of its natural-gas-fired electrical peaking plants (Watford City, ND – Lonesome Creek Station used in the initial analysis). Because Basin Electric's plants are peaking plants, they do not run at full capacity, so the plant design had to account for this. Depending on the capacity factor, which dictates the thermal energy available for desalination, up to about 50,000 bbl/day of wastewater could be treated, which represents approximately 3% of the total produced water volume in North Dakota currently. We worked with Basin Electric to gather capacity data for the plant and perform the design accordingly. The design of that facility was intended only to produce distilled water and a dry salt product.

Triple 8 contracted with Barr to investigate the technical feasibility of incorporating an additional process into the design concept to supplement the economics of recovering the lithium with a low-risk revenue stream. The Barr team recommended production of caustic soda using the chlor-alkali process. The chlor-alkali process requires a high purity supply of water and salt, so the earlier UND design for producing distilled water and salt was adapted to the new process. The goal is to utilize as much as possible the exhaust energy from the combustion turbine generators (CTGs) when it is available, while enabling the continuous production of saleable product.

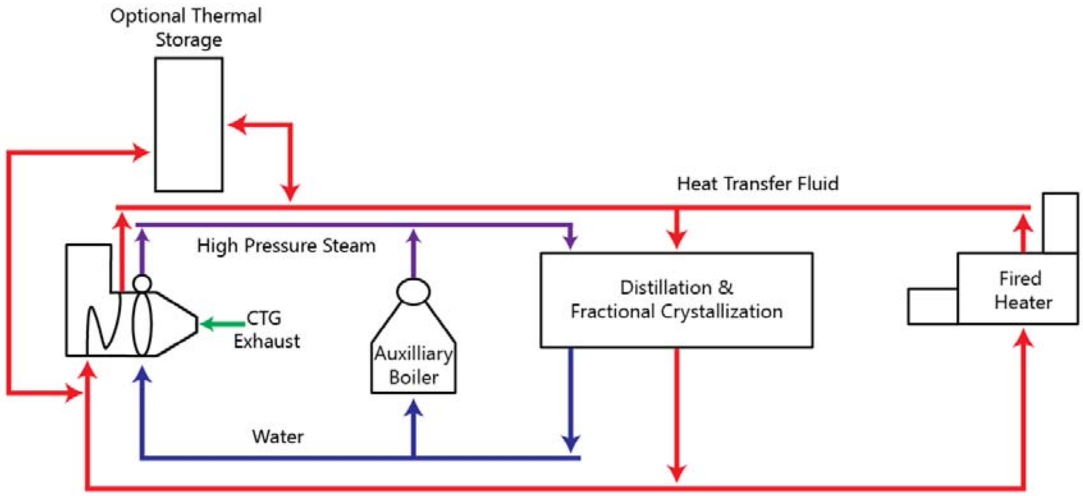

Figure 4. Block Flow Diagram of the process heat supply

Figure 4 is a simplified schematic of the coordinated heat supply system for the distillation and fractional crystallization process. During periods when the CTGs are running, maximum use will be made of the available exhaust energy. Steam will be generated in the heat recovery steam generator (HRSG) at about 500 psig. This high pressure is desirable to make the use of thermal vapor compression feasible. The heat needed for distillation and evaporation is much lower in temperature and a system to circulate a heat transfer fluid (HTF) will be used. A thermal storage tank for hot HTF may be included if it shows to be economically attractive. During periods when the CTGs are not operating, hot HTF can be supplied from the thermal storage tank or from a fired heater, and steam will be supplied from the auxiliary boiler.

We also began work on evaluating a few possible process technologies for use in this facility. This work is not yet complete, but preliminary results have identified no fatal flaws, and all steps in the process can be accomplished with commercially available equipment. Based on processing 50,000 bbl/day, the potential revenue from each product is shown in Table 3 below.

Table 3. Potential Revenue of Products

Material	Maximum production[1]	global pricing	Hypothetical maximum revenue[2]
Caustic Soda (NaOH)	2700	$550/T	$420 M
Hydrochloric acid (35 w% HCl)	4000	$200/T	$290 M
magnesium metal	6	$2000	$4.6 M
bromine	4.1	$5000/T	$13 M
lithium carbonate	10.2	$8500	$10 M
rubidium metal	0.071	$10.7mil/T	$0.6 M

Notes: 1. short tons/year, based on 50,000 bbl/day and 360 day/ year operation
2. millions of US dollars/year at 2017 pricing

Summary of Relevant Previous Experience by the Project Team

Barr's team, is led by Dr. Scott Korom, who was a faculty member in Geology and Geological Engineering at UND for 20 years. The Barr team has considerable experience with salt water disposal, water treatment, and industrial facility design, in multiple sectors, such as the power industry, the oil and gas industry, mining and the chemicals industry. Barr will be able to effectively design and evaluate multiple plant concepts that have promising potential, both for economic viability and expedited commercialization. In addition, Barr is very familiar with current methods of lithium mining and production and has evaluated the feasibility of commercial deposits and production operations.

The UND team, led by Dr. Daniel Laudal, has extensive experience in extractive metallurgy of rare earth elements, synthesis and use of adsorbents for liquid- and gas-phase separations, and hydrometallurgy for metals concentration/purification. Dr. Laudal is currently leading or a key member of multiple efforts investigating methods of extraction and concentration of rare earth elements (REE) and other valuable metals (including lithium) from North Dakota lignite coals and combustion fly ash. Dr. Xiaodong Hou, who is an inorganic and analytical chemist with extensive experience on lithium chemistry and aqueous inorganic chemistry will be leading the work on lithium recovery. His current work is focused on use of a novel method for production of improved cathode materials for lithium ion batteries. Dr. Hou is also very experienced with the use of ion exchange membranes and other types of ion exchange processes. Dr. Hou's experience is very well suited towards development of the salts separation and purification steps that are proposed.

In addition to the technical team consisting of UND and Barr, this project will be supported by Triple 8 LLC and its commercialization partner Dr. Ben Rostron from Isobrine Solutions. Isobrine was founded based on the extensive sampling and characterization by Dr. Rostron on Williston Basin formation waters [16, 17, 18]. Dr. Rostron is, to our understanding, considered the foremost expert on Williston Basin formation water chemistry, and has fully characterized samples from over 2,000 wells in the Basin (includes full list of major, minor and trace species). Dr. Rostron is excited to support Triple 8 and the project team on this effort, as his work has identified lithium as a particularly attractive recovery target, with certain zones and formations in the Basin having concentrations exceeding 200 mg/L – exceptionally high levels for typical oil producing formations. Triple 8 LLC is providing in-kind cost share support to this project and will participate in project activities through market research, venture strategy development, permitting and mineral rights research, and generally participating in project meetings and advising the project team.

MANAGEMENT

This project will be led by principle investigator, Dr. Scott Korom. Dr. Korom joined Barr in 2014 as a senior environmental engineer after 20 years as a professor of geological engineering at the University of North Dakota, where he taught courses on hydrogeology, groundwater monitoring and remediation, soil mechanics, groundwater modeling, contaminant hydrogeology, water sampling and analysis, and geological engineering design. From 2012 to 2014, Scott served as director of UND's Institute of Energy Study's Underground Coal Gasification team and led a diverse group of researchers in an effort to develop this technology in North Dakota. Through his research and projects, Scott has worked with federal and North Dakota state regulators and industries on hydrogeology and water-quality issues. His client base at Barr includes organizations associated with saltwater disposal wells, geochemistry, agriculture, coal-fired power generation, and oil and gas refining. Scott has written more than 20 publications in peer-reviewed, archival journals and has given more than 100 professional presentations.

Richard Hardegger, P.E. (Minnesota), Vice President for Barr, will be the point of contact for project sponsors and co-sponsors and will maintain regular communications. The project timetable is presented in the next section of this document, but Dr. Korom will be in charge of maintaining the project schedule.

The process modelling and laboratory analysis at UND will be managed by Dr. Daniel Laudal. Dr. Laudal is the Major Projects Manager at the UND IES and is well qualified to lead this project. Dr. Laudal reports to the UND IES executive director, Dr. Michael Mann. Dr. Laudal will work closely with Dr. Mann to verify that all personnel and resources are available to efficiently conduct the project.

At the completion of the project, the team will work with project sponsors, co-sponsors, and supporters to devise the plan for the next steps in bringing this technology to market.

TIMETABLE

The project Gantt chart is shown in Figure 5. Task 1, the Market Analysis is currently underway and being completed by Triple 8. We expect to start immediately on development of the Basis of Design document, (Task 2) before the market study has concluded. Tasks 3, 4, and 5 will commence when the Market Analysis and Basis of Design are finalized. Overall, we are scheduling for a 12-month project beginning on or around April 1, 2018. The schedule will be adjusted accordingly depending on the actual award date. The major milestones are established as follows, along with dates of submission of key deliverables and interim reports:

1) completion of Task 1 and Task 2 (Month 3)
2) interim status report (Month 7)
3) draft report with conceptual design 80% complete (Month 10)
4) final project report, including integrated process design and capital cost expectation (Month 12)

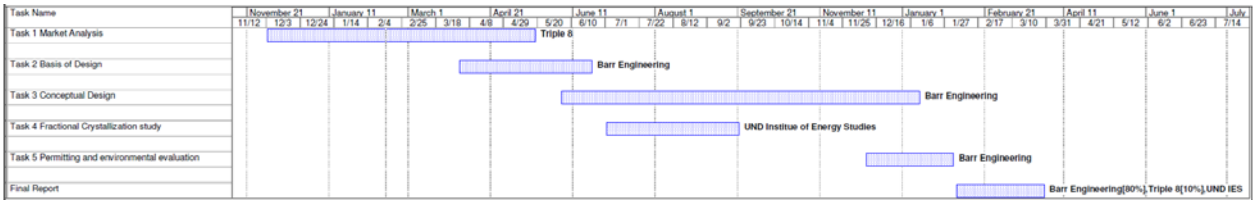

Figure 5. Project Gantt chart showing the timeline for completion of each of the project tasks

BUDGET

The budget breakdown for the proposed project is provided in Appendix A. We have committed cost share totaling 50% of the project cost. Triple 8 LLC has received commitment from the City of Williston (see attached letter of support) for the amount of $75,000 in cash, which Triple 8 will commit to the proposed project. In addition, Triple 8 will provide in-kind services associated with its participation in project activities, valued at $35,000 as detailed in its letter of support. The subcontract for UND is detailed in its attached letter of support and proposal to Barr.

In the event of less funding availability from NDIC than requested in this proposal, the project can still proceed but with some reductions in the scope of work. This reduction would be associated with Task 3 and Task 5. Depending on the magnitude of the reduction, we still expect that the project objectives could be obtained; however, we feel the project scope and budget as proposed will produce the facility definition needed to attract further funding at project completion, and enable it to move into Front End Engineering and Design (FEED).

CONFIDENTIAL INFORMATION

No confidential information has been included with this application.

PATENTS/RIGHTS TO TECHNICAL DATA

UND and Triple 8 LLC have filed a provisional patent based on the concept's development to date and wish to reserve rights to any additional intellectual property (IP) stemming from the development efforts to date. UND also wishes to protect any technical data generated during completion of the proposed project and any new IP resulting.

STATUS OF ONGOING PROJECTS (IF ANY)

No currently ongoing projects at Barr or the UND IES are being funded by the Oil & Gas Research Program.

Appendix A – Budget Justification

Barr Engineering Co. – Budget Justification

Proposed Budget Breakdown

Cost Category	Total Project	NDIC Share	Triple 8 In-kind	Triple 8 Cash
Salary	$135,000			
Travel	0			
Subcontracts	$50,000			
In-kind Cost Share			$35,000	
Total Project	$220,000	$110,000	$35,000	$75,000

Our estimate to complete the tasks as described in the scope of work and based on the support from Triple 8 and UND is shown below.

- Task 1 $35,000 by Triple 8
- Task 2 $13,000 by Barr
- Task 3 $78,000 by Barr
- Task 4 $50,000 by UND
- Task 5 $16,500 by Barr
- Task 6 $27,500 by Barr

Barr Engineering Co.'s standard rate sheet for 2018 is provided below and followed by budget breakdown for UND. Triple 8's financial commitment is included with its letter of support found in Appendix D.

BARR

Fee Schedule—2018

Rev. 12/30/17

Description	**Rate* (U.S. dollars)**
Principal	$145-295
Consultant/Advisor	$155-250
Engineer/Scientist/Specialist III	$125-150
Engineer/Scientist/Specialist II	$95-120
Engineer/Scientist/Specialist I	$65-90
Technician III	$125-150
Technician II	$95-120
Technician I	$50-90
Support Personnel II	$95-150
Support Personnel I	$50-90

Rates for litigation support services will include a 30% surcharge.

A ten percent (10%) markup will be added to subcontracts for professional support and construction services to cover overhead and insurance surcharge expenses.

Invoices are payable within 30 days of the date of the invoice. Any amount not paid within 30 days shall bear interest from the date 10 days after the date of the invoice at a rate equal to the lesser of 18 percent per annum or the highest rate allowed by applicable law.

Reimbursable expenses including, but not limited to, the actual and reasonable costs of transportation, meals, lodging, parking costs, postage, and shipping charges will be billed at actual cost. Materials and supplies charges, printing charges, and equipment rental charges will be billed in accordance with Barr's standard rate schedules. Mileage will be billed at the IRS-allowable rate.

Principal category includes consultants, advisors, engineers, scientists, and specialists who are officers of the company.

Consultant/Advisor category includes experienced personnel in a variety of fields. These professionals typically have advanced background in their areas of practice and include engineers, engineering specialists, scientists, related technical professionals, and professionals in complementary service areas such as communications and public affairs.

Engineer/Scientist/Specialist categories include registered professionals and professionals in training (e.g. engineers, geologists, and landscape architects), and graduates of engineering and science degree programs.

Technician category includes CADD operators, construction observers, cost estimators, data management technicians, designers, drafters, engineering technicians, interns, safety technicians, surveyors, and water, air, and waste samplers.

Support Personnel category includes information management, project accounting, report production, word processing, and other project support personnel.

*Rates do not include sales tax on services that may be required in some jurisdictions.

Budget Justification

University of North Dakota Institute for Energy Studies

Labor:

The key personnel on the project are Drs. Laudal, Barse and Hou. Each has management and technical roles that are defined in the attached letter of support. A graduate student will support the project by performing the majority of the experimental work with guidance from the project leads. The following is a breakdown of the labor costs associated with completion of the scope of work.

Note that hours of labor are only used for proposal purposes. The University tracks employee's time on projects on the basis of effort. Actual salary for specific personnel have been used, and average salary for generic labor categories have been used.

Category	Hours	Rate	Total Cost
Laudal	80	40.87	3,270
Barse	100	34.77	3,477
Hou	100	28.52	2,852
Graduate Student	397	21.15	8,393
Administrative	20	22.00	440
TOTAL			**18,431**

Fringe Benefits:

Fringe benefits have been estimated based upon historical averages. For staff, an average of 40% of salary has been used. For the graduate student an average of 5% of salary has been used. These estimates are used only for proposal purposes. Upon award, only the true costs of each employee's fringe benefits package will be charged to the project. Based on these estimates, the total fringe benefits requested is $4,435.

Supplies:

Supplies costs of $5,000 are requested which is an estimate based on previous experience and the scope of work. Supplies for laboratory testing, such as glassware, filters, sample storage, and reagents will be required. Additionally, project reporting costs such as paper, folders, logbooks…etc have been estimated and included. Additionally, based upon the estimated usage on the project, we are requesting partial support of the IES' Aspen Plus software license. This partial support has been estimated at 25% of the annual license cost, or $500.

Analytical:

To support the laboratory testing in the project, analytical testing is required. We anticipate the following breakdown. The costs for each type of analysis are based on the standard rates for the UND Materials Characterization Laboratory.

Analytical	#	Rate	Total
XRD, XRF, SEM	35	103	3,605
ICP-MS	10	300	3,000
Sample Prep	20	75	1,500
Total			**8,105**

XRD: X-ray diffraction
XRF: X-ray fluorescence
SEM: Scanning electron microscopy
ICP-MS: Inductively coupled plasma – mass spectrometry

Indirect Costs:

UND uses the modified total direct cost method, which is defined as the total direct costs minus equipment expenditures exceeding $5,000 and subcontracts in excess of the first $25,000. For this proposal, the federally negotiated rate of 39% has been used. Total indirect costs requested are $14,029.

Budget Summary:

The table below breaks down the major budget categories.

Category	Cost
Salaries	18,431
Fringe Benefits	4,435
Total Labor	22,866
Supplies	5,000
Analytical	8,105
Total Direct Costs	35,971
Indirect Costs	14,029
Total Project Cost	**50,000**

Appendix B - References

[1] N. Kruger and North Dakota Department of Mineral Resources, "A "Rare Opportunity"," January 2016. [Online]. Available: https://www.dmr.nd.gov/ndgs/documents/newsletter/Winter%202015/A%20Rare%20Opportunity.pdf.

[2] N. D. S. G. -. O. &. G. Division, "North Dakota Drilling and Production Statistics," [Online]. Available: https://www.dmr.nd.gov/oilgas/stats/historicaloilprodstats.pdf.

[3] J. W. Bader, "The Dakota Group - An Important Geologic Unit for Produced Water from Oil and Gas Development in North Dakota," North Dakota Geological Survey, January 2016.

[4] D. E. Garrett, Handbook of lithium and natural calcium chloride, Elsevier Academic Press, 2004.

[5] B. A. Kurz, D. J. Stepan, K. A. Glazewski, B. G. Stevens, T. E. Doll, J. T. Kovacevich and C. A. Wocken, "A review of Bakken water management practices and potential outlook," Energy and Environmental Research Center, Grand Forks, ND, 2016.

[6] U.S. Department of Energy, "Critical Materials Strategy," U.S. Department of Energy, 2011.

[7] U.S. Geological Survey, "Mineral Commodities Summary - Magnesium," 2018.

[8] U.S. Geologic Summary, "Mineral Commodities Summary - Lithium," 2018.

[9] R. M. Horner, C. B. Harto, R. B. Jackson, E. R. Lowry, A. R. Brandt, T. W. Yeskoo, D. J. Murphy and C. E. Clark, "Water use and management in the Bakken shale oil play in North Dakota," *Environmental Science and Technology,* vol. 50, pp. 3275-3282, 2016.

[10] N. E. Lauer, J. S. Harkness and A. Vengosh, "Brine spills associated with unconventional oil development in North Dakota," *Environmental Science & Technology,* vol. 50, pp. 5389-5397, 2016.

[11] M. Gallucci, "Fracking wastewater is changing the earth's subsurface, study finds," [Online]. Available: http://mashable.com/2016/09/22/earthquakes-wastewater-disposal-study/#pAHWegRqdqqm. [Accessed October 2017].

[12] L. Geiver, "Halliburton unveils frack water recycling process for Bakken," *The Bakken Magazine,* 14 August 2013.

[13] D. J. Stepan, R. E. Shockey, B. A. Kurz, N. S. Kalenze, R. M. Cowan, J. J. Zinman and J. A. Harju, "Bakken water opportunities assessment - Phase I," Energy & Environmental Research Center, Grand Forks, ND, 2010.

[14] MGX Minerals, Inc., "Press Releases," [Online]. Available: https://www.mgxminerals.com/investors/news/2017.html. [Accessed October 2017].

[15] B. J. Rostron, L. I. Kelley, L. K. Kreis and C. Holmden, "Economic potential of formation brines: Interim results from the Saskatchewan brine sampling program," in *Summary of Investigations 2002, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2002-4.2, CD-ROM, Paper C-1, 29p*, Saskatchewan Geological Survey, 2002.

[16] G. K. Jensen, "Initial results of a brine sampling project: Investigating the mineral potential of brines in Southeastern Saskatchewan," in *Summary of Investigations 2012, Volume 1, Saskatchewan Geological Survey, Sask. Ministry of the Economy, Misc. Rep. 2012-4.1, Paper A-8, 8p*, 2012.

[17] Isobrine Solutions, "Resources," [Online]. Available: http://isobrine.com/resources/. [Accessed October 2017].

[18] Wealth Daily, "Special Report: 3 stocks for lithium's 1000% trend," [Online]. Available: https://www.wealthdaily.com/report/3-stocks-for-lithiums-1000-trend/1642. [Accessed October 2017].

Appendix C – Resumes of Key Personnel

RICHARD HARDEGGER, PE, QEP
Vice President, Senior Environmental Engineer

BARR

Experience

Rich has 27 years of experience managing projects involving air emissions permitting, environmental review, environmental compliance auditing, and waste remediation. His work at Barr has included:

- Managing New Source Review (NSR) applicability determinations and complex project permitting at industrial facilities for clients in the utility, food-processing, steelmaking, and mining and ore-processing industries.
- Directing environmental review projects.
- Managing environmental compliance audits of industrial facilities.
- Performing best available control technology (BACT) reviews for combustion sources.
- Leading emission-source testing projects.

Rich's project experience in specific areas includes:

Air Quality

- Preparing a Prevention of Significant Deterioration (PSD) air permit application for a 99 MW lignite-fired combined heat-and-power facility that provides process steam to ethanol and malting plants. The project uses a circulating fluidized-bed boiler with spray-dry and baghouse control of acid gases and particulates and selective non-catalytic reduction (SNCR) for NOx control. Three gas- or oil-fired auxiliary boilers provide backup and peaking capacity.
- Managing environmental approvals for the installation of a 170 MW gas- and oil-fired peaking turbine at an existing RDF-fired power plant. Key regulatory hurdles involved cumulative impacts from air emissions deposition on area lakes, and subsequent human-health risks. Work included conducting a study focused on metal and persistent organic-compound emissions from the existing RDF boilers; the study showed that emissions occurred at less than background levels.
- Managing engineering cost-estimate development for demonstration-scale solid sorbent-based carbon-capture process for coal-fired boiler system.
- Preparing engineering cost estimates for air-pollution-control equipment, including thermal oxidizers, electrostatic precipitators, scrubbers, baghouses, cyclones, and injection systems for NOx, SO_2, and mercury emissions control.
- Providing permitting assistance to a three-facility dairy operation with waste-to-energy systems based on anaerobic digestion of manure and biogas-fired engines to generate about 2 MW of power. Air permitting and compliance aspects included PSD applicability determination, coordination of NSPS compliance testing, modeling against short-term ambient standards, Title V permit application, and permit negotiation support.
- Providing on-site assistance to the environmental staff of a large utility to facilitate the expediting of numerous air-permit modification applications. The modifications included adding new equipment, increasing equipment capacity, and conducting test burns of alternative fuels.

- Managing the preparation of a PSD air permit application for a 1.2 million-ton-per-year integrated steel-making operation. Air emission sources included mining, taconite pellet production, direct reduced iron, electric arc furnaces, and rolling mill. Close proximity of the plant and mining operations to residential properties and to Class I protected areas presented significant challenges to dispersion modeling and health-risk assessment analyses.
- Managing emission-source testing projects for utility, mining, and manufacturing sources. EPA test methods used for criteria and hazardous-air-pollutant (HAP) sampling and analysis. Prepared a PSD permit application for a six-unit gas-fired simple-cycle power plant in southern Minnesota. Key efforts were centered on BACT determination for NOx control.
- Preparing an emission inventory and Minnesota registration permit application for a barley malting facility. Emission sources included grain handling, combustion, and malt-handling equipment.
- Providing environmental compliance guidance for a multi-facility animal-feed manufacturing company, including stormwater management, spill-prevention planning, and air quality permitting. The animal feed is manufactured from waste food products fed through a drying system fired by biomass and recovered packaging materials. Firing the packaging materials requires compliance with waste-combustor rules, as well as continuous monitoring for proper combustion conditions.
- Preparing Title V permit applications for two wood-milling facilities in Wisconsin. Emission sources were primarily wood processing equipment (particulate) and wood preserving processes (VOCs).
- Reviewing a permit application submitted to the MPCA for a proposed ethanol production facility. The review was conducted under the expedited permit program, which enables the state to contract for assistance paid for by the permittee. The review and draft permit involved several exchanges of inquiries and explanation over the course of three weeks.
- As part of an audit team, performing environmental audits for a recreational-vehicle manufacturing plant. The audit addressed hazardous and solid waste, air emissions, wastewater treatment and discharge, stormwater discharge, SARA, and remedial compliance issues. The audit also reviewed corporate environmental management systems.
- Assisting a small utility with preparing and implementing a monitoring plan for Title IV (Acid Rain Program) requirements. The monitoring plan was based on excepted monitoring options that the program offers for peak generating plants. An upgrade of the plant's control-system software was required to produce quarterly reports in an electronic format acceptable to the Acid Rain Division data-handling system.
- Preparing Title V air permit applications for 17 power generation facilities: coal-burning power plants, gas-turbine peaking stations, refuse-derived fuel (RDF) plants, and engine generators.
- Conducting an air emission inventory for a metal fabrication facility that included foundry, heat-treating, machining, plating, painting, welding, and miscellaneous

support operations. Inventoried 1,100 sources for their respective criteria and HAP emissions before preparing a Title V permit application.

- Assisting in the preparation of PSD and air permit applications. Performed associated emission calculations and reviews of best available control technology (BACT) for operations such as refinery catalytic cracking, iron-mining industrial furnaces, and incinerators for NOx, CO, particulate, SO_2, and VOC emission control.
- As an audit team member with a focus on air quality compliance, performing environmental audits for animal-rendering plants in Minnesota, Montana, Maryland, Michigan, Nebraska, Kansas, Iowa, Illinois, and California. The primary concern related to air at most of the facilities was compliance with odor-control requirements. Rendering facilities usually also have air-quality compliance issues related to process and boiler upgrades, process and combustion emissions, material-handling emissions, fuel tanks, and truck-fleet operations.
- Performing an environmental audit for a bakery-waste recycling facility in Kansas. Primary operations reviewed included raw-material receiving, rotary-drum-dryer processing, milling and screening, and storage and shipping.
- Preparing construction permit applications for five turbine-driven natural gas compressors. The new compressors were part of a natural-gas pipeline expansion project that required permits to be issued in time for contracts for gas to be honored.

Environmental Review

- Manager for EIS preparation for a 1.2 million-ton-per-year integrated steelmaking project that included all aspects from mining iron ore to finished steel. Key issues addressed included air emission impacts on Class I areas of Northern Minnesota, ultimate water discharge impacts to the Mississippi River and modeled impacts on human health and ecology.
- Coordinating the preparation of an EAW for a 6 MW anaerobic digestion-based power project. The project is defined as a fuel conversion facility, which is a mandatory EAW category in Minnesota. The project will be primarily challenged by wastewater discharge limitations, whether as a direct discharge or via the POTW. Potential odor emissions and the impacts of significant new truck traffic are also addressed by the EAW.
- Coordinating the preparation of an EAW for a animal-feed drying process fired by packaging materials separated from off-specification food products. Initial determinations aligned the process with those of a solid-waste combustor. While still under dispute, the determination triggers the EAW requirement for new waste combustors in Minnesota. A beneficial-use determination for the solid fuel material is being sought in parallel.

Waste Remediation

- For transportation purposes, classifying hazardous waste from 3M facilities nationwide according to U.S. Department of Transportation and Environ-mental Protection Agency (Resource Conservation and Recovery Act) programs. The hundreds of waste streams classified included those of multiple-hazard class, reportable quantities for hazardous substances, and spent materials. Many chemicals encountered were not identified in the Hazardous Materials Table (49 CFR 172.101) and subsequently required classification based on product information, regulatory guidance, and professional judgment.

- Hazardous waste packaging and labeling per the lab-pack provisions of the Department of Transportation for 3M center facilities. Coordination of special waste shipments with ET&S and the corporate incinerator.
- Preparing engineering cost estimates for site remediation technologies for a used-oil re-refinery site. Evaluated incineration, stabilization, bioremediation, boiler and industrial furnace recycling, Resource Conservation and Recovery Act landfilling, and soil-washing technologies.
- Designing waste-material handling in support of on-site hazardous waste incineration. Coordinated an on-site field study of material-handling techniques that successfully amended tarry waste material to a manageable form. Field-study results were incorporated into the pre-design activities for material handling and on-site incineration of acidic and lead-bearing tar waste.
- Assisting in the development of treatability studies of thermal-desorption and soil-washing technologies for remediation of a former manufactured-gas-plant site.
- Participating in a detailed analysis of site remediation technologies according to National Contingency Plan criteria to support an Environmental Protection Agency record-of-decision amendment request.
- Participating in an air-pathway analysis for air toxics at a used-oil re-refinery site. To obtain air emissions data, the analysis employed flux-chamber testing of HAPs from source material through various stages of a pretreatment system. This information was essential to completion of a risk assessment for material-handling activities related to site remediation.

Education

BS, Chemical Engineering, South Dakota School of Mines and Technology, 1991

BS, Dairy Manufacturing, South Dakota State University, 1980

Registrations

Environmental Engineer: Minnesota, Alberta, Michigan

Qualified Environmental Professional: Institute of Professional Environmental Practice (IPEP)

Memberships

Association of Professional Engineers and Geoscientists of Alberta (APEGA)

Air & Waste Management Association

Minnesota Society of Professional Engineers

Institute of Professional Environmental Practice

BARR

Experience

Scott joined Barr in 2014 as a senior environmental engineer after 20 years as a professor of geological engineering at the University of North Dakota, where he taught courses on hydrogeology, groundwater monitoring and remediation, soil mechanics, groundwater modeling, contaminant hydrogeology, design hydrology for wetlands, water sampling and analysis, and geological engineering design. From 2012 to 2014, Scott served as director of UND's Underground Coal Gasification team and led a diverse group of researchers in an effort to develop this technology in North Dakota.

Through his research and projects, Scott has worked with North Dakota regulators and industries on groundwater and water quality issues. His research has focused on the unique properties of the state's outwash aquifers, soil and groundwater remediation, groundwater denitrification, contaminant transport, and hydrogeological challenges associated with energy development. Scott has written more than 20 publications in peer-reviewed, archival journals and has given more than 100 professional presentations. His work experience has included:

- Serving as certifying engineer for a groundwater monitoring system designed for compliance with the Environmental Protection Agency (EPA) coal combustion residuals rule.
- Serving as project manager for a groundwater monitoring system designed for compliance with the EPA coal combustion residuals rule.
- Serving as engineer of record for the upgrade of groundwater capture trenches at a refinery.
- Serving as liaison to the University of North Dakota on a project studying rare earth elements in coal and associated geologic materials.
- Serving as project manager for site selection of an underground storage facility for refined petroleum products.
- Developing computer solutions for the influence of multiple injection wells in a sandstone formation for a salt-water disposal-well permit application and managing the well permit-application process.
- Serving as science advisor on agriculture-related water-quality issues.
- Directing the University of North Dakota's Underground Coal Gasification program.
- Directing the University of North Dakota's Geological Engineering program.
- Directing the University of North Dakota's Environmental Analytical Research Laboratory.
- Serving as expert witness for cases involving overland flooding of university buildings, flooding of a wetland, and the contamination of agricultural land by brine and petroleum.
- Directing projects involving groundwater denitrification in Minnesota, North Dakota, and Iowa.

- Directing a project involving groundwater denitrification around Lake Taupo, North Island, New Zealand.
- Serving as expert witness concerning the hydraulic analysis of the flooding of a university's steam tunnels.
- Serving as expert witness for a lawsuit concerning contamination of groundwater and agricultural land with brine.
- Directing a project on the variation of groundwater entrance velocities through a well screen.
- Serving as a postdoctoral research fellow for The Department of Energy. Worked on a strategy to use field-scale tracer tests to determine physical and chemical properties of contaminated aquifers that require remediation in Aiken, South Carolina.
- Serving as a research engineer and groundwater hydrologist at Utah State University for a research project evaluating the effectiveness of the remediation at a U.S. EPA Superfund site in Libby, Montana. This was the first Superfund site to be granted approval by the EPA to attempt in-situ bioremediation of contaminated groundwater. The aquifer at this site is contaminated with toxic wood-preserving wastes (PCP and PAHs). Research focused on the competition between remediating bacteria and reduced inorganic species for oxygen injected (as hydrogen peroxide) into the aquifer as an electron acceptor.
- Serving as a research assistant at Utah State University. Work included:
  - A project with the Utah Division of Water Quality on the transport of nutrients in the groundwater of an agricultural valley. This work included monitoring wells and vadose zone samplers, conducting groundwater tracer tests in the field, modeling nitrogen losses via denitrification in agricultural wastes leaching into an aquifer, and producing the final project report.
  - A project with the U.S. Geological Survey on salt diffusion from a marine shale underlying an irrigated hill slope. This included field work, groundwater quality modeling with SUTRA (Saturated and Unsaturated Transport), and writing the quarterly and final technical completion reports. Fieldwork included monitor-well installation, scheduled well sampling, surveying, and taking hydraulic conductivity measurements with a Guelph permeameter.
- Serving as research assistant for the University of Akron. Conducted a laboratory model study funded by the Ohio Department of Transportation and the Federal Highway Administration on energy dissipators for culverts and assisted in producing the final project report. This analysis resulted in a design procedure that is used by the Ohio Department of Transportation to design "hydraulic jump chambers."
- Serving as a consultant for Computer Modeling, Inc., in Cuyahoga Falls, Ohio. Assisted in the modeling of municipal water distribution systems (AKWA). This included data procurement, data entry into the model, and model calibration with use of field tests.

Education PhD, Civil and Environmental Engineering, Utah State University, Logan, 1991

MS, Civil Engineering, University of Akron, Ohio, 1984

BS, Civil Engineering, University of Akron, Ohio, 1982

Registration

Professional Engineer: North Dakota

Certification

Underground Coal Gasification, UCG Association, London, 2013

PHREEQC-2, U.S. Geological Survey, Amsterdam, 2000

Wetland Delineator Certification Training Program, U.S. Army Corps of Engineers, 1997

OSHA 40-Hour HAZWOPER and 8-Hour Refreshers, 1991-1994

Awards

Keynote Speaker. 2013 Workshop on the Role of Groundwater Nitrogen Assimilation in Catchment Water Management – Importance and Uncertainties. University of Wakaito, New Zealand.

Keynote Speaker. 58th Annual Midwest Ground Water Conference. September 23-25, 2013. Bismarck, North Dakota.

Best Presentation Award. International Association of Hydrogeologists 40th International Congress. September 15-20, 2013. Perth, Australia.

University of North Dakota North Dakota Spirit Faculty Achievement Award, 2011 and 2008.

Outstanding Practice and Education Paper for 1990, Publications Committee for the *Journal of Irrigation and Drainage Engineering*, American Society of Civil Engineers.

Affiliations

American Geophysical Union

American Society of Civil Engineers

National Ground Water Association

Tau Beta Pi National Engineering Honor Society

Books

Korom, S.F. 2010. *Nutrients in the Elk Valley Aquifer: A Primer on Denitrification.* Saabrücken, Germany: LAP Lambert Academic Publishing.

Simon, A.L., and S.F. Korom. 2002. *Hydraulics*, 5th ed. Safety Harbor, FL: Simon Publications.

Simon, A.L., and S.F. Korom. 1996. Instructor's Manual for *Hydraulics*, 4th ed. Upper Saddle River, NJ: Prentice-Hall.

Simon, A.L., and S.F. Korom. 1996. *Hydraulics*, 4th ed. Upper Saddle River, NJ: Prentice-Hall.

Publications in Archival Journals

Pei, P., S.F. Korom, K. Ling, and J. Nasah. 2014. Cost comparison of syngas production from natural gas conversion and underground coal gasification. *Mitigation and Adaptation Strategies for Global Change*, DOI 10.1007/s11027-014-9588-x.

Derby, N.E., S.F. Korom, and F.X.M. Casey. 2013. Field-scale relationships among soil properties and shallow groundwater quality. *Ground Water* 51(3): 373-384.

Korom, S.F., and J.C. Seaman. 2012. When "conservative" anionic tracers aren't. *Ground Water* 50(6): 820-824.

Jabbari, H., Z. Zeng, S.F. Korom, and M. Khavanin. 2012. Well test analysis in dual-porosity aquifers with stress-dependent conductivity. *Research Journal of Environmental and Earth Sciences* 4(11): 962-981.

Korom, S.F., W.M. Schuh, T. Tesfay, and E.J. Spencer. 2012. Aquifer denitrification and in situ mesocosms: Modeling electron donor contributions and measuring rates. *Journal of Hydrology* 432-433: 112-126.

Gerla, P.J., M.U. Sharif, and S.F. Korom. 2011. Geochemical processes controlling the spatial distribution of selenium in soil and water, west central South Dakota, USA. *Environmental Earth Sciences* 62(7): 1551-1560.

Korom, S.F. 2010. Graphical solutions for hillslopes: Discharge, head and velocity diagrams. *Journal of Irrigation and Drainage Engineering* 136(8): 563-566.

Korom, S.F., A.J. Schlag, W.M. Schuh, and A.K. Schlag. 2010. Erratum for in situ mescocosms: Denitrification in the Elk Valley Aquifer. *Ground Water Monitoring and Remediation* 30(4): 142.

Korom, S.F., and E.J. Dodak. 2009. Numerical study of bromide as a tracer for aquifer macrodispersivity tests: Comparing conservative behavior to mildly nonlinear adsorption. *Journal of Hydrologic Engineering* 14(12): 1383-1389.

Korom, S.F., A.J. Schlag, W.M. Schuh, and A.K. Schlag. 2005. In situ mesocosms: Denitrification in the Elk Valley Aquifer. Ground Water Monitoring and Remediation 25(1): 79-89.

Korom, S.F., K.F. Bekker, and O.J. Helweg. 2003. Influence of pump intake location on well efficiency. *Journal of Hydrologic Engineering* 8(4): 197-203.

James, L.D., and S.F. Korom. 2001. Lessons from Grand Forks: Planning nonstructural flood control measures. *Natural Hazards Review* 2(4): 182-192.

James, L.D., and S.F. Korom. 2001. Lessons from Grand Forks: Planning structural flood control measures. *Natural Hazards Review* 2(1): 22-32.

Korom, S.F. 2000. An adsorption isotherm for bromide. *Water Resources Research* 36(7): 1969-1974. 2000.

Seaman, J.C., P.M. Bertsch, S.F. Korom, and W. P. Miller. 1996. Physicochemical controls on non-conservative anion migration in coarse-textured alluvial sediments. Ground Water 34(5): 778-783.

Korom, S.F., M.J. McFarland, and R. Sims. 1996. Reduced sediments: A factor in the design of subsurface oxidant delivery systems. *Ground Water Monitoring and Remediation* 16(1): 100-105.

Korom, S.F., and R.W. Jeppson. 1994. Nutrient leaching from alfalfa irrigated with municipal wastewater. *Journal of Environmental Engineering* 120(5): 1067-1081.

Korom, S.F., and R.W. Jeppson. 1994. Nitrate contamination from dairy lagoons constructed in coarse alluvial deposits. *Journal of Environmental Quality* 23(5): 973-976.

Korom, S.F. 1992. Natural denitrification in the saturated zone: A review. *Water Resources Research* 28(6): 1657-1668.

Korom, S.F. 1991. Comment on "Modeling of multicomponent transport with microbial transformation in groundwater: The Fuhrberg case" by E. O. Frind et al. *Water Resources Research* 27(12): 3271-3274.

Korom, S.F., S. Sarikelle, and A.L. Simon. 1991. Closure (for design of hydraulic jump chambers). *Journal of Irrigation and Drainage Engineering* 117(6): 980-982.

Korom, S.F., S. Sarikelle, and A.L. Simon. 1990. Design of hydraulic jump chambers. *Journal of Irrigation and Drainage Engineering* 116(2): 143-153.

Simon, A.L., S. Sarikelle, and S.F. Korom. 1987. Internal energy dissipators for culverts on steep slopes with inlet control. *Transportation Research Record* 1151: 25-31.

Other Publications

Scott has written or co-written more than 100 additional publications, including abstracts from professional presentations. A select list is provided below:

Korom, S.F., P. Pei, and J. Nasah. 2014. *Status Report 3 for Geomechanical Study of*

Harmon Lignite and Surrounding Rocks for Underground Coal Gasification in Western North Dakota.

Krieger, A., S. F. Korom, and W. Schuh. 2013. Electron donor contributions to denitrification in the Elk Valley aquifer, North Dakota. *58th Annual Midwest Ground Water Conference Program with Abstracts*. Bismarck, ND. September 23-25, 2013.

Korom, S. 2013. Underground coal gasification: What is it and what role does hydrogeology play? *58th Annual Midwest Ground Water Conference Program with Abstracts*. Bismarck, ND. September 23-25, 2013.

Korom, S.F. 2013. Evaluating groundwater denitrification potential and characteristics with in situ mesocosms. *International Association of Hydrogeologists 40th International Congress Programs & Abstracts Book* 727: 62. Perth, Australia.

Hadfield, J., and S. Korom. 2013. Groundwater denitrification in the Lake Taupo catchment, New Zealand. *International Association of Hydrogeologists 40th International Congress Programs & Abstracts Book* 519: 62. Perth, Australia.

Korom, S.F. 2013. Fracking does not put N.D. groundwater a serious risk. *Grand Forks Herald* op-ed. Grand Forks: ND: C5. July 28, 2013.

Maharjan, B., S.F. Korom, and E.A. Smith. 2013. Electron donor concentrations in sediments and sediment properties at the agricultural chemicals team research site near New Providence, Iowa, 2006-2007. *U.S. Geological Survey Data Series* 737: 17.

Hadfield, J.C., and S.F. Korom. 2012. Mechanisms of groundwater denitrification, Lake Taupo, New Zealand. Hydrological Society Conference. Nelson, New Zealand. November 27-30, 2012.

Korom, S.F. 2012. Modeling the electron donor contributions to aquifer denitrification: Karlsruhe, ND. *57th Annual Midwest Ground Water Conference Program with Abstracts*. Minneapolis, MN. October 1 -3, 2012.

Benson, S.A., J. Nasah, C. Thumbi, S. Patwardhan, L. Yarbrough, H. Feilen, S.F. Korom, and S. Srinivasachar. 2012. Evaluation of scrubber additives and carbon capture injection to increase mercury capture. Submitted to the Minnesota Department of Natural Resources. August 2012.

Korom, S.F., and W.M. Schuh. 2012. Aquifer denitrification in the upper Midwest: Are there groundwater denitrifying hotspots in your area? National Ground Water Association Focus Conference on Midwestern Groundwater Issues. Columbus, OH. June 26-27, 2012.

Korom, S.F., and J.C. Hadfield. 2012. Lake Taupo, New Zealand: Kiwis worry about nitrogen too. *24th Annual Environmental and Ground Water Quality Conference Program with Abstracts*. Pierre, SD. March 21, 2012.

Xu, H., R. Ashu, T. Grage, B. Kistner, S. Patwardhan, A. Pesaran, and S.F. Korom. 2011. An extraction technique for the analysis of Fe (II) in silicate minerals in sediments. Poster. *23st Annual Environmental and Ground Water Quality Conference Program with Abstracts*. Pierre, SD. March 23-24, 2011.

Korom, S.F. 2011. Are Fe (II) silicates more important to groundwater quality than previously reported? *23st Annual Environmental and Ground Water Quality Conference Program with Abstracts*. Pierre, SD. March 23-24, 2011.

Christenson, C.J., and S.F. Korom. 2010. Denitrification at the Oakes Irrigation Test Area, Dickey County, ND. *North Dakota EPSCoR 2010 State Conference, Grand Forks, Abstract 166*. September 29, 2010.

Schlag, A.K., S.F. Korom, and F.X.M. Casey. 2009. Management of agricultural tile drains influences by manganese deposits and insights into other biofilm issues. U.S. Department of the Interior, Bureau of Reclamation. December, 2009.

Korom, S.F., and T. Tesfay. 2009. Modeling groundwater-quality data from in-situ mesocosms using PHREEQC to provide insights into the electron donors involved in denitrification in the Karlsruhe Aquifer, ND. *EOS, Transactions, American Geophysical Union, 90(52), Fall Meeting Supplement, Abstract* H31C-0798.

Korom, S.F., and R.J.S. Klapperich. 2009. Why are the sediments of some regional aquifers more reactive than others? *21st Annual Environmental and Ground Water Quality Conference Program with Abstracts, Pierre, SD*. March 18-19, 2009.

Spencer, E., and S. Korom. 2008. Isotopic tracers as evidence of denitrification in the Karlsruhe Aquifer. *Technical Report No. ND08-01*. North Dakota Water Resources Research Institute, North Dakota State University.

Korom, S.F. 2007. Aquifer denitrification: Is it a zero-order or first-order reaction? *EOS, Transactions, American Geophysical Union 88(52) Fall Meeting Supplement, Abstract* H54D-08.

Klapperich, R.J.S., and S.F. Korom. 2007. Electron donor potential of eastern North Dakota *shale formations. EOS, Transactions, American Geophysical Union 88(52) Fall Meeting Supplement, Abstract* H13G-1676.

Justham, T.F., Hartman, J.H., and Korom, S.F. 2007. Using poorly preserved Hell Creek Formation mussels to interpret paleoenvironments. *Geological Society of America Annual Meeting, Abstracts with Programs* 39:6. Denver, CO, Oct 28-31, 2007.

Schuh, W.M., S. Bottrell, S. Korom, J. Gallagher, and J. Patch. 2006. Sources and processes affecting the distribution of dissolved sulfate in the Elk Valley Aquifer. *Water Resources Investigation No. 38*. North Dakota State Water Commission, Bismarck, ND.

Sharif, M., P.J. Gerla, and S.F. Korom. 2003. Effect of geochemical processes and environment on selenium in soil and water at the Hovland Ranch, central South Dakota. 2003 ASA-CSSA-SSSA Annual Meetings. Denver, CO, November 2-6, 2003.

Durbin, H., T. Tesfay, and S.F. Korom. 2003. Predicting denitrification capabilities of Karlsruhe aquifer sediments based on data provided from our network of in situ mesocosms. *47th Annual Midwest Ground Water Conference Program with Abstracts*. Fargo, ND, October 2-4, 2002.

Korom, S.F. 2002. *Analysis of Pumping Test Data for Well near Fertile, MN*. Report for Lako Drilling, Arthur, ND.

Durbin, H., and S.F. Korom, Assessment of the Denitrification Capacity of the Sediments of the Karlsruhe Aquifer, in Preliminary Analysis of Nitrate-N Loads and Causes of Nitrate-N Loading in the Karlsruhe and New Rockford Aquifers Near Karlsruhe, North Dakota in 2001, North Dakota State Water Commission in cooperation with the North Dakota Department of Health, February 25, 2002.

Korom, S.F. 2001. *Hydraulic Analysis of the NDSU Steam Tunnel Flood of June 2000*. Preliminary report for EAPC, Grand Forks, ND.

Korom, S. 2001. Groundwater quality in Red River Valley aquifers. *Land, Water, and People: Partners for a Sustainable Future, Abstracts and Information Resources for the 18th Annual Red River Basin Land and Water International Summit Conference* 5. January 16-18, 2001.

Korom, S.F., K. Bekker, and O.J. Helweg. 2000. Comparison of numerical and physical model results: Velocity distribution on a well screen. *Building Partnerships: Proceedings of the ASCE 2000 Joint Conference on Water Resources Engineering and Water Resources Planning & Management*. July 30-August 2, 2000.

James, L.D., S. Korom, and G. Galloway. 1999. Practical lessons learned from the Grand Forks flood. *ASCE's 1999 International Water Resource Engineering Presentation Summaries* 445. August 8-12, 1999.

Jones, J.P., P.J. Gerla, and S.F. Korom. 1998. Stochastic analysis of three-dimensional, heterogeneous capture zones. *Proceedings of the MODFLOW '98 International Conference, Vol. 2*. October 4-8, 1998.

Korom, S.F., and E. Dodak. 1998. Comparison of conservative plume transport to plumes undergoing weakly non-linear adsorption. *EOS, Transactions, American Geophysical Union/Supplement* 79(17). April 28, 1998.

Korom, S.F. 1997. Influence of detrital shale on denitrification in the deltaic aquifers of ancient Lake Agassiz. Joint EPSCoR Conference, Brookings, SD. September 27, 1997.

Dodak, E., and S.F. Korom. Numerical evaluation of bromide as a tracer for macrodispersivity experiments in anion-sorbing sediments. *EOS, Transactions, American Geophysical Union/Supplement* 77(17). April 23, 1996.

Korom, S.F., C.J. Munson, and G.G. Mayer. 1996. Denitrification by pyrite: Comparison of the Elk Valley Aquifer to northern European aquifers. Proceedings of the Fifth Biennial North Dakota Water Quality Symposium, Bismarck, ND. March 20-21, 1996.

Gerla, P.J., and S.F. Korom. 1995. *EM Conductivity Survey: Selected Aareas of the Fossaa Farm, Mountrail County, North Dakota, Phase II Report*.

Korom, S.F. 1993. Bromide plume behavior in anion-adsorbing aquifer sediments. *EOS, Transactions, American Geophysical Union/Supplement* 74(43), October 26, 1993.

Korom, S.F. 1991. Denitrification in the unconsolidated deposits of the Heber Valley aquifer. Ph.D. dissertation. Utah State University, Logan, UT.

Jeppson, R.W., J. Mclean, C.G. Clyde, and, S.F. Korom. 1991. *Studies Related to Nutrients Entering Groundwater from the Heber Valley Sewer Farm and Dairies*. Utah Water Research Laboratory, Utah State University.

Duffy, C.J., J.J. Jurinak, S.F. Korom, J. McCalpin, and P. Corey. 1989. Groundwater investigation of SO_4 = diffusion from a Cretaceous shale hillslope: Upper Colorado River Basin. *Technical Completion Report to the U.S. Geological Survey*.

Korom, S.F. 1984. Optimum Design of Internal Energy Dissipators for Culverts Operating Under Inlet Control. MS thesis. University of Akron. 1984.

Experience

Don has 25 years of engineering, operations, and construction experience, primarily in the power and petrochemical industries. He provides assistance on all phases of projects from permitting support, engineering, and procurement through construction, startup, operations, and maintenance. Don's experience encompasses a variety of power generation processes, including combustion-turbine combined cycles, fluidized beds, pulverized coal steam cycles, reciprocating engines, and cogeneration systems. His petrochemical project experience includes distillation, scrubbing, absorption, and various reaction processes. Examples of Don's work include:

- Conducting a third-party review for Minnkota Power Cooperative involving solutions to a vibration problem on its Unit 2 forced-draft fans. The work entailed reviewing and interpreting test reports, analyzing performance data, and evaluating correction options.
- Serving as a process engineer for two years at Kestrel Engineering Group in Bismarck, North Dakota, where he worked on various projects for power and petrochemicals clients. He developed, designed, and commissioned a novel ammonia recovery process for a refinery in Montana, which resulted in reduced air emissions, improved NaHS product purity, and a saleable fertilizer stream.
- Serving as a factory engineer for two years at Sidney Sugar in Sidney, Montana, where he managed large capital projects, wrote specifications and procedures, and assisted operations and maintenance personnel with repairs and upgrades.
- Serving in a variety of engineering roles for 10 years at WorleyParsons in Reading, Pennsylvania.
    - As a technical consultant, he conducted feasibility studies, performed long-range forecasting, and supported performance testing for domestic and international clients.
    - As an engineering manager of the mechanical engineering department of the non-nuclear division in Sofia, Bulgaria, Don managed the development of design guides and work processes; provided training and mentoring, supervised engineering studies, reports, and drawings; verified compliance to standards and procedures; and assisted with implementation of new document control process.
    - As a principal engineer, Don supported new project development and feasibility studies, including preliminary plant design, definition of equipment operating conditions, equipment sizing, performance calculations estimates, alternate fuel studies, and performance enhancement options analysis. He performed calculations for air and water permits including emissions rates, fuel consumption, water consumptive use, and reagent usage. Don provided technical support and consulting services for existing plants including repowering studies, performance testing, energy auditing, upgrade option analysis, site support during emissions controls upgrade projects, and on-site operator training. Through technology sharing arrangements with joint partners, he assisted by demonstrating work processes, methodologies, and procedures, and adapting design guides to meet engineers' needs for a 1000 MW combined cycle plant in Korea using a once-

through cooling system and burning LNG and for a 1000 MW supercritical coal fired plant in China.

- Serving as plant manager for one year at Renewable Biofuels in Houston, Texas, where he was responsible for safe, efficient, and profitable operation of the largest biodiesel production facility in the U.S. During the first year of operation, Don solved many reliability problems and corrected some design flaws.
- Serving as operations supervisor for five years at Parsons Corporation in Pasadena, California, where he oversaw the operation and maintenance of UCLA's chiller/co-generation facility, which provides steam and electrical power to 50,000 residents and a hospital. Don arranged maintenance and repair activities, oversaw daily operations, supervised 17 engineers, scheduled all contractors, implemented design changes to improve operability of plant, trained new engineers in plant operation and maintenance, and provided troubleshooting of civil, mechanical, electrical, and control systems.
- Serving as third assistant engineer for two years at the Military Sealift Command in Oakland, California, where he performed daily maintenance on boilers, steam turbines, distillers, air compressors, refrigeration compressors, purifiers, pumps, and valves on cargo ships carrying supplies for the U.S. Navy. Don also held responsibility for all plant operations during his watch, supervised unlicensed personnel in repairs and overhauls of machinery, oversaw repairs by shipyard personnel, and performed quality control.

Education BS Marine Engineering, United States Merchant Marine Academy, 1991

Registration Professional Engineer: North Dakota, Maryland

Certifications Montana Waste Water Operator

U.S. Coast Guard, Second Assistant Engineer of Steam and Motor Vessels (any horsepower)

Publications/ Presentations

"The Limits to Renewable Energy," Energy Pulse, 2008

"Pulling Out All the Stops for Plant Efficiency," Electric Power Expo, 2007

"The Trend Toward On-Site Power Generation," Energy Pulse, 2007

"Future Trends in Electric Power Generation," PowerGen, 2006

"Techniques to Minimize Time and Stress During HRSG Start-Up," PowerGen, 2003

"Repowering Considerations for Converting Existing Power Plants to Combined Cycle Power Plants," AMSE IJPGC, 2002

"Recent Trends in Equipment Selection for Combined Cycle Power Plants," ASME IJPGC, 2001

Training Heat and Mass Balance Calculations

Performance Testing and Analysis of Equipment Operation and Condition

ROB C. WAGNER, EIT
Chemical Engineer

BARR

Experience

Rob assists clients with projects involving pipelines, oil-well production, petroleum refining, bioenergy, mining, metal and ore production, and process automation and control. He participates in a variety of environmental consulting projects, contributing to client-specific solutions for meeting the requirements of local, state, and federal air and water regulatory programs. Rob's work includes:

- Conducting mass balance calculations and emission inventories.
- Evaluating and troubleshooting new and existing systems.
- Preparing quarterly, semiannual, and annual regulatory reports for fuels clients
- Providing regulatory assistance including preparing draft National Pollutant Discharge Elimination System (NPDES) permit applications, air quality permit applications, and related documents.
- Developing plans for compliance monitoring, waste management, spill prevention, and risk management.
- Conducting technical and economic feasibility studies for pollution-control equipment and processes.

Before joining Barr, Rob gained industry experience through internships in:

- *Petroleum engineering.* At a private energy company, Rob produced detailed well logs; subsurface-anomaly models; and potential reservoir models. He also researched and engineered a completion strategy for newly leased land and wells; conducted drilling and well-stimulation processes in the field; and assisted with production forecasting and optimization and decline-curve analysis.
- *Process engineering.* At a food processing company, as part of a process-safety management program, Rob gained experience writing and revising dozens of SOP (standard operating procedure) documents pertaining to plant equipment. In addition, he wrote and revised engineering documents to facilitate ongoing mechanical-integrity testing of process vessels and piping, and created piping and instrumentation diagrams.
- *Project management.* At an engineering firm, he coordinated the work of multiple contractors to best ensure on-schedule project completion; wrote detailed daily technical reports; and worked closely with engineers to resolve on-site issues and maintain project progress.

Education

BS, Chemical Engineering, University of North Dakota, 2016

Registration

Engineer in Training: North Dakota

Software

MicroStation

MATLAB

Aspen (Plus and HYSYS)

Golden Software (Strater, Voxler, Surfer)

AMANDA GRAVSETH
Environmental Permitting and Compliance Engineer

BARR

Experience

Amanda helps clients achieve compliance with environmental regulations while meeting corporate objectives for production and profitability. With six years of experience working in ethanol-production and agricultural-processing facilities, she offers clients practical insights into local, state, and federal programs governing air and water quality.

Her assistance encompasses:

- Performing mass balance calculations
- Conducting emission inventories
- Evaluating and troubleshooting systems
- Drafting permit applications
- Analyzing regulatory and technical issues
- Preparing plans for compliance monitoring
- Conducting technical and economic feasibility studies for pollution-control equipment and processes
- Providing on-site and remote compliance assistance
- Negotiating with regulatory agencies

Amanda’s background includes working for Cargill, Inc., in the following capacities:

- **Ethanol production supervisor.** Managed day-to-day production rates for Cargill Starch and Sweeteners North America’s largest grind contributor. Led team of operation technicians; developed financial budgets and cost-saving initiatives; and supervised shutdown and maintenance planning.
- **Process optimization engineer.** For Cargill’s feed enterprise, championed optimization initiatives that resulted in $7 million annual savings. Also developed OSHA process-safety management efforts for an ammonia chiller system and managed optimization work for an expansion of the company’s custom-blend feed production.
- **Capital project engineer.** Supervised chemical unloading efforts and staff at Cargill’s Blair, Nebraska, facility and supported plant startups in Iowa and Louisiana.

Amanda began her career as an intern at Tesoro’s refinery in Mandan, North Dakota, analyzing real-time data to optimize systems.

Education

BS, Chemical Engineering (minor: mathematics), University of North Dakota, 2011

***Curriculum Vitae:* Daniel A. Laudal**

Principal Areas of Expertise

Dr. Laudal's principal areas of expertise include extractive metallurgy, rare earth element recovery processes, coal geochemistry, CO_2 capture, adsorbent-based processes, advanced power generation systems and emissions control. He has specifically focused on process and equipment design and has worked with numerous types of lab, bench and pilot-scale systems. Dr. Laudal has ten years of experience managing and executing large multidisciplinary and multi-organizational research projects.

Education and Training

University of North Dakota	Chemical Engineering	B.S. 2006
University of North Dakota	Chemical Engineering	Ph.D. 2017

Research and Professional Experience

2016-Present Manager: Major Projects, UND Institute for Energy Studies.

Roles include developing and writing funding proposals, managing research projects, coordinating IES research staff and students, and process design/development of innovative solutions to challenges in the energy industry. Primary research areas include recovery of rare earth elements and other valuable metals/minerals from coal and coal byproducts and aqueous waste streams, chemical looping combustion, post-combustion CO_2 capture, novel gas/solid contacting reactor designs, and development of novel designs for the aging fleet of North Dakota University System steam generation plants.

2012-2015 Research Engineer, UND Institute for Energy Studies.

Research areas included CO_2 capture, advanced fuel conversion systems and natural gas processing. Work included concept development, process design and testing of innovative solid-sorbent based technologies. Principal Investigator on multiple projects and key contributor on several successful research proposals. Lead research engineer on multiple projects relating to Chemical Looping Combustion (CLC) Technology. Developed concepts for innovative methods to characterize both the physical attrition and reactivity of oxygen carriers for CLC. Co-developer of a unique technology for segregation of oxygen carriers and fuel combustion products (ash, unburned char) in CLC, a significant challenge in advancing the technology. Developing new oxygen carrier compositions and optimizing process conditions to maximize fuel conversion and increase carrier durability. Lead research engineer developing UND's solid sorbent-based CACHYS™ technology for post-combustion CO_2 capture. Led the design, construction and testing of the small pilot-scale slipstream test system installed at the UND steam plant. Co-inventor and lead developer of a novel sorbent-based technology for capture and processing of associated natural gas for reduction of gas flaring from oil fields.

2008-2012 Research Engineer, UND Energy & Environmental Research Center.

Research involved design and operation of various lab and pilot-scale gasification, combustion and advanced power systems. Lead researcher on a project aimed at developing a process for the production of hydrogen by catalytic hydrolysis of biomass. Gained invaluable experience with high pressure and high temperature systems and fluidized beds.

2006-2008 Field Engineer, Schlumberger Oilfield Services.

Design, execution and evaluation of well cementing operations in the Williston Basin. Lead a team of 3-5 operators in performing various types of cement and work-over operations. Lead cement lab operator – designed, tested and validated cement compositions for each job.

Publications/Presentations

Laudal, D.; Benson, S. “Recovery of Rare Earth Elements from North Dakota Lignite Coal and Related Feedstocks.” Conference Proceedings: 2017 Clearwater Clean Energy Conference. June 2017, Clearwater, Florida.

Van der Watt, J., **Laudal, D.** “Development of a spouted bed reactor for chemical looping combustion.” Conference Proceedings: 2017 Clearwater Clean Energy Conference. June 2017, Clearwater, Florida.

Feilen, H., **Laudal, D.** “Development of an advanced oxygen carrier attrition characterization methodology for chemical looping combustion.” Conference Proceedings: 2017 Clearwater Clean Energy Conference. June 2017, Clearwater, Florida.

Benson, S., **Laudal, D.** “Investigation of rare earth element extraction from North Dakota coal-related feedstocks.” 2017 NETL Crosscutting Research & Analysis Portfolio Review. March 2017, Pittsburgh, PA.

Pei, P., Nasah, J., Solc, J., Korom, S. **Laudal, D**., Barse, K. “Investigation of the feasibility of underground coal gasification in North Dakota, United States.” Energy Conversion and Management. Volume 113, 1 April 2016, pages 95-103.

Pei, P., **Laudal, D**., Nasah, J., Johnson, S., Ling, K. “Utilization of Aquifer Storage in Flare Gas Reduction.” Journal of Natural Gas Science and Engineering. Volume 27, Part 2, November 2015, 1100-1108.

Benson, S., Srinivasachar, S., **Laudal, D**. “CO_2 Capture Using Hybrid Sorption with Solid Sorbents (CACHYS^{TM})”. Thirteenth Annual Conference on Carbon Capture, Utilization & Storage. April 2014.

Emerson, S., Zhu, T., Davis, T. Peles, A., She, Y., Willigan, R., Vanderspurt, T., Swanson, M., **Laudal**, **D**. "Liquid Phase Reforming of Woody Biomass to Hydrogen". International Journal of Hydrogen Energy, August 2013.

Synergistic Activities

Introduction to Mineral Processing Short Course – Colorado School of Mines

- Completed 2.0 Continuing Education Units – July, 2016

Proposal Reviewer

- University Coalition for Fossil Energy Research

Faculty Mentor in the Alice T. Clark Program

- Mentored new mechanical engineering faculty (2016/2017) related to research and grant writing

Provided Testimony in Support of Senate Bill 2196 to the ND House Appropriations Committee

- Technical testimony to support the Valley City State University carbon plant funding bill

Patents Pending

Rare Earth Element Extraction from Coal: Filed 03/17/2017; Application # 15/462,164

Xiaodong Hou PhD

Education and Training

2010-2013 **Postdoctoral**, Chemistry Department, University of North Dakota, Grand Forks, ND, USA.
2009 **Ph.D.** **Polymer Chemistry and Physics**, Shanghai Jiao Tong University, Shanghai, China.
2005 **M.S.** **Chemical Engineering**, Shaanxi University of Science and Technology, Shaanxi, China.
2002 **B.S.** **Chemical Engineering**, Shaanxi University of Science and Technology Shaanxi, China

Research and Professional Experience

2014-present **Analytical Chemist/Lecturer** Advanced Material Characterization laboratory, Institute for Energy Studies, UND. Research interests: 1) development of advanced energetic materials (eg. cathode materials for Lithium ion battery) using diverse chemistry approaches: organic chemistry, polymer chemistry and inorganic chemistry, and 2) using or modifying analytical techniques to determine the chemical, mineral, and microscopic mechanical characteristics of a variety of materials, including coal, rock, mineral, metal, catalyst, scale, and polymer etc. Analytical instruments include scanning electron microscopy with energy-dispersive spectroscopy (SEM-EDS), wavelength-dispersive x-ray fluorescence spectroscopy (WDXRF), x-ray diffraction (XRD) and nanoindenter with scanning probing microscopy (SPM).

2013-2014 **Interim Lab Director** and **Analytical Chemist** Environmental Analytical and Research Laboratory, UND. Principal areas of expertise and research interest include analytical techniques, including spectroscopic, chromatographic and microscopic techniques to determine the chemical components of a variety of environment samples. Assist in student training and teaching course *Water Sampling and Analysis,* Geol 540.

2010-2013 **Postdoctoral Research Associate**, Chemistry Department, University of North Dakota, Grand Forks, ND. Research interests focus on synthesis and characterization of covalently bonded hierarchical organic-polymeric nanomaterials, such as nanosheet, nanofiber, and polymeric Ladders. Major work involved in developing analytical techniques to characterize these novel materials to which traditional methods aren't applicable.

2009 **Application Scientist**, Shimadzu Corporation, Shanghai, China. Principal responsibility includes developing analytical methodologies for samples from a broad range of customers. Analytical techniques include spectroscopic instruments such as FT-IR, UV, Atomic Absorption spectroscopy (AAS) and inductively coupled plasma optical emission spectrometer (ICP-OES).

2005-2009 **PhD Research**
Research area: synthesis and characterization of highly ordered inorganic nanoparticles/block copolymer hybrid materials. Mainly using microscopy and X-ray techniques such as atomic force microscopy(AFM), scanning probe microscopy (SPM), TEM, SEM and small angel x-ray scattering (SAXS), intensive research focus on the effect of the surficial chemistry on the agglomeration behavior/distribution of inorganic nanoparticles within polymer matrix, effect of molecular structure of block copolymer on the microscopic phase structure, interaction of different loading of inorganic nanoparticle with polymer matrix, and micro-phase separation behavior originated from supramolecular self-assembly, interfacial forces and interaction.

2002-2005 MS research
Research interests focus on preparation, physical and mechanical properties of composite materials of

cellulose and collagen recovered from chrome-containing leather waste.

Professional Training

- "Yangtze River Delta Region AFM/SPM Technology Seminar" sponsored by Veeco Ltd., Shanghai Normal University, July 8, 2008.
- "Synchronic irradiation and its application" sponsored by Natural Science Foundation of China, Shanghai Institute of Applied Physics, Shanghai, August 18-22, 2008

PUBLICATIONS

1. Wang, Z.; Randazzo, K.; **Hou, X.**; Simpson, J.; Struppe, J.; Ugrinov, A.; Kastern, B.; Wysocki, E.; Chu, Q. R. Stereoregular Two-Dimensional Polymers Constructed by Topochemical Polymerization. *Macromolecules*, **2015**, 48, 2894-2900. http://pubs.acs.org/doi/abs/10.1021/acs.macromol.5b00109

2. **Xiaodong Hou**, Zhihan Wang, Joseph Lee, Erin Wysocki, Casey Oian, and Qianli R. Chu. Synthesis of Polymeric Ladders from Plant-Derived Starting Materials. *Chem. Comm.*, **2014,** *50*, 1218-1220**.** http://pubs.rsc.org/en/content/articlepdf/2013/cc/c3cc47379a

3. **Xiaodong Hou**, Zhihan Wang, Molly Overby, Angel Ugrinov, Casey Oian, Rajiv K. Singh, and Qianli 'Rick' Chua. A Flexible Organic Nanosheet Framework that Accommodates and Releases Guest Molecules. *Chem. Comm.*, **2014**, *50*, 5209-5211. http://pubs.rsc.org/en/content/articlehtml/2014/cc/c3cc47159d

4. Chen, J., Wu, X., **Hou, X.**, Su, X., Chu, Q., Fahruddin, N., & Zhao, J. X. Shape-tunable hollow silica nanomaterials based on a soft-templating method and their application as a drug carrier. *ACS Appl. Mater. Interfaces*, **2014**, *6*, 21921-21930. http://pubs.acs.org/doi/full/10.1021/am507642t

5. **Xiaodong Hou,** Qiaobo Li, and Amin Cao. Solvent Annealing-Induced Microphase-Separation of Polystyrene-b-Polylactide Block Copolymer Aimed at Preparation of Ordered Nanoparticles/Block Copolymer Hybrid Thin Film. *Journal of Polymer Research*, **2014**, *21:*491. http://link.springer.com/article/10.1007%2Fs10965-014-0491-7

6. **Xiaodong Hou,** Qiaobo Li, Lin Jia, Yang Li, Yingdan Zhu and Amin Cao. Synthesis and Microphase-Separation of Polystyrene-b-Polylactide Block Copolymers Aimed at Preparation of Ordered Nanoparticles/Block Copolymer Hybrid Materials. *Polymer International*, **2014**, 63:1159-1167. *http://link.springer.com/article/10.1007%2Fs10965-014-0491-7*

7. **Xiaodong Hou,** Qiaobo Li, Lin Jia, Yang Li, Yingdan Zhu and Amin Cao. In-situ Self-assembly of enantiomeric Diblock Poly(styrene)-*b*-Poly(lactide) Via Stereocomplexation in Non-selective Solvents. *Macromolecular Chemistry and Physics* **2013**, *214*, 1569−1579. *http://onlinelibrary.wiley.com/doi/10.1002/pi.4746/full*

8. **Xiaodong Hou,** Matthew Schober, Qianli Chu. A Chiral Nanosheet Connected by Amide Hydrogen Bonds. *Crystal Design & Growth*, **2012**, *12*, 5159–5163. http://pubs.acs.org/doi/full/10.1021/cg301030f

9. **Xiaodong Hou**, Qiaobo Li, Lin Jia, Yang Li, Yingdan Zhu and Amin Cao. New Preparation of Structurally Symmetric, Biodegradable Poly(L-lactide) Disulfides and PLLA–Stabilized, Photoluminescent CdSeQuantum Dots. *Macromolecular Bioscience*, **2009**, *9*, 551-562. http://onlinelibrary.wiley.com/doi/10.1002/mabi.200800312/full

10. **Xiaodong Hou**, Qiaobo Li, Lin Jia, Yang Li, Yingdan Zhu and Amin Cao. Visualization of Spontaneous Stereocomplex Aggregates by Diblock Poly(styrene)-b-Poly(l-lactide)s and Poly(d-lactide)s With New Fluorescent CdSe Quantum Dot Labels. *Journal of Polymer Science: Part B: Polymer Physics*, **2009**, *47*, 1393–1405. http://onlinelibrary.wiley.com/doi/10.1002/polb.21741/full

Kirtipal A. Barse, Ph. D., P.E.

Research Engineer, Institute for Energy Studies, University of North Dakota

Education and Training

University of Pune	Chemical Engineering	B.S. 2006
University of North Dakota	Chemical Engineering	M.S. 2009
University of North Dakota	Chemical Engineering	Ph.D. 2014

Professional Experience

2013–Present: Research Engineer, UND Institute for Energy Studies

Primarily responsible for evaluating new technologies and performing techno-economic feasibilities. Other responsibilities include process modeling using Aspen Plus and HYSYS, developing mass and energy balances, process design, design review, develop cost estimates and economic analysis. Past project areas include power generation using low temperature oilfield brines and waste heat recovery, integration of steam plant with activated carbon plant, CO_2 capture technologies, and crude oil conditioning. Current research interest includes treatment of oilfield brines using supercritical water treatment to achieve zero liquid discharge.

2006–2012: Graduate Research Assistant, UND Department of Chemical Engineering

Performed process modeling of the Organic Rankine Cycle to evaluate the technical and economic feasibility of using low temperature geothermal resources to produce electricity. Evaluated the performance of various working fluids and configurations for the Organic Rankine Cycle.

Lead researcher to develop a novel biodegradable polymer with enhanced properties. Responsible for researching reaction schemes, reaction conditions, synthesis and characterization of the polymers. Performed polymer characterization to determine their physical, thermal and mechanical properties.

Publications

- Barse, K. A., & Mann, M. D. (2016). Maximizing ORC performance with optimal match of working fluid with system design. Applied Thermal Engineering, 100, 11–19.
- Barse, K. A., McDonald, M. R., & Crowell, A. M. (2012). Evaluation of the geothermal potential in the Rio Grande Rift: Truth or Consequences, New Mexico. In Transactions - Geothermal Resources Council (Vol. 36 2, pp. 1315–1320).
- Gosnold, W. D., Barse, K. A., Bubach, B., Crowell, A., Crowell, J., Jabbari, H., Wang, D. (2013). Co-Produced Geothermal Resources and EGS in the Williston Basin, GRC Transactions, 37, 1–6.
- Pei, P., Barse, K. A., Gil, A. J., & Nasah, J. (2014). Waste heat recovery in CO_2 compression. International Journal of Greenhouse Gas Control, 30, 86–96.
- Pei, P., Barse, K. A., & Nasah, J. (2016). Competitiveness and Cost Sensitivity Study of Underground Coal Gasification Combined Cycle Using Lignite. Energy & Fuels, acs.energyfuels.6b00019.
- Pei, P., Nasah, J., Solc, J., Korom, S. F., Laudal, D., & Barse, K. A., (2016). Investigation of the feasibility of underground coal gasification in North Dakota, United States. Energy Conversion and Management, 113, 95–103.
- Crowell, J., Crowell, A., McDonald, M. R., Barse, K. A., Bubach, B., Dahal, S., Zimny, E. (2011). Evaluation of Geothermal Potential for Selected Resources in the Rio Grande Rift: Donna Ana County. GSA Annual Meeting, 2011.

Appendix D – Letters of Support from Cost Share Sponsors and Participants

Tom Bachmeier of OneCor Services, LLC

John Jacobs of Basin Electric Power Cooperative

James Powers of Powers Energy Corporation

Steve Kemp and Karla Kemp of Triple 8, LLC

Dr. Michael Mann and Dr. Barry Milavetz, University of North Dakota Institute for Energy Studie

Wyatt Black of Creedence Energy Servicess

OneCor SERVICES

PO Box 893 Williston, ND 58802
606 East Dakota Parkway Williston, ND 58801
www.onecor.com
(701) 774-1105 Office (701) 572-4444 Fax

February 14th, 2018

To: Scott F. Korom, PhD, PE
Barr Engineering Co.
234 West Century Avenue
Bismarck, ND 58503

From: Tom Bachmeier
General Manager
OneCor Services, LLC.

Re: Support for proposal entitled "Oilfield produced water purification with chemicals production and valuable metals recover" submitted to: North Dakota Oil & Gas Research Program—North Dakota Industrial Commission.

Dear Dr. Korom,

On behalf of OneCor Services, LLC, we fully support the proposal stated above.

OneCor Services has a very strong interest in the HCl acid as a byproduct of the process from the water purification. We blend and sell HCl acid that is purchased from several sources and having a local manufacturer of HCl will increase our strength with our customers as well as improve logistics to receive our raw HCl product.

We currently are using 400,000 gallons per month of Raw HCl Acid and sourcing from several states away via rail or truck. By having a local source, we would be able to decrease costs by 15%-20% and obtain a larger market share by competitive pricing.

We intend to fully work with Triple 8 and partner with them to utilize this byproduct as a part of our raw material.

Call me with any questions or concerns,

Sincerely,

Tom Bachmeier
General Manager
OneCor Services, LLC
701-471-4210
tbachmeier@onecor.com

November 9, 2017

Dr. Dan Laudal
Manager, Major Projects
Institute for Energy Studies
University of North Dakota
Grand Forks, ND 58202

RE: Support for proposal entitled "Oilfield produced water purification with chemicals production and valuable metals recovery" submitted to: North Dakota Oil & Gas Research Program – North Dakota Industrial Commission.

Dear Dr. Laudal:

Basin Electric Power Cooperative is pleased to provide this letter of support for the University of North Dakota's (UND) team project investigating a combination of processes to purify high total dissolved solids (TDS) oilfield wastewaters, produce bulk commodity chemicals with high volume local markets, and recover and concentrate valuable elements/minerals such as lithium. The proposed approach will drastically reduce the cost of thermal energy required to purify the water and recover the solids.

We understand that the UND team will partner with Barr Engineering on this effort to perform an initial technology screening assessment to evaluate options for generation of fresh water and bulk commodity chemicals. Based on this initial assessment, we understand that the UND team will test methods at the laboratory-scale to recover and concentrate valuable metals contained in the mixed salts that could be integrated with the purification and chemicals production systems. We also understand that the project has been set up to expedite the commercialization of the fresh water production and chemicals production plant components, as these are industrially ready processes, but that need to be demonstrated and optimized for high TDS Williston Basin brines. A complementary effort looking at metals recovery from the dissolved solids is included as well, but is considered a longer-term commercialization effort that will need laboratory-scale development with subsequent scale up. However, the value-added recovery of metals such as lithium can potentially add significant value to the overall plant and can also help satisfy the fast growing markets for lithium for lithium ion batteries.

Basin Electric is a not-for-profit generation and transmission cooperative incorporated in 1961 to provide supplemental power to a consortium of 137 rural electric cooperatives, providing electricity to 2.9 million consumers. Members are included in nine states with a total operation of 5,205 MW and capacity of 6,555 MW of electricity. Basin also owns over two thousand miles of transmission lines. Basin Electric owns and operates the Pioneer Generation Station near Williston, ND, and the Lonesome Creek Station near Watford City, ND, which are natural gas fueled electrical generation facilities.

We understand that the proposed technology will investigate the utilization of waste heat sources to reduce the cost of wastewater desalination. The Pioneer Station and Lonesome Creek Station have high temperature waste exhaust gas from their simple cycle gas turbines that would be an ideal source of heat for the proposed technology. In addition, these facilities are located in the heart of the oil production in the Williston Basin, making transport of the wastewater to the facility, and transport of the fresh water product from the facility simpler. Basin Electric has previously provided data to the UND team on the flue gas properties (temperature, pressure, flow, composition) from these facilities, which was used in the initial technology concept evaluation by a UND chemical engineering senior design project. Basin Electric will support the proposed project by providing, as needed, additional plant information that will be required for the project. We will follow the progress of the project, and if successful, will be interested in collaborating with the UND team on a larger-scale demonstration and potential commercialization in North Dakota.

We wish the UND team success in this proposal effort, and look forward to collaborating on this opportunity.

Sincerely,

John W. Jacobs

John W. Jacobs
Senior Vice President, Operations

bh/lg
cc: Kevin Tschosik
Benjamin Hertz
James Sheldon

Powers Energy Corporation
P.O. Box 1221
Williston, North Dakota 58802-1221

February 15, 2018

Scott F. Korom, PhD, PE
Senior Environmental Engineer
Barr Engineering Co.
234 West Century Avenue
Bismarck, ND 58503

RE: "Oilfield produced water purification with chemicals production and valuable metals recover" submitted to: North Dakota Oil & Gas Research Program – NDIC.

Dear. Dr. Korom:

I write in support of the University of North Dakota's team project referenced above. This possibility to process oilfield waste waters, produce important chemicals and recover elements and minerals economically is truly exciting. I sincerely hope that the effort will receive total support from all our state agencies and the private sector.

I grew up in Williston, where I continue to have an office with my brother, Tom Powers, and have been involved in the oil business in North Dakota for over 40 years. We were one of the first in the Bakken play in Mountrail County, where we put together the group to drill the first well there, the EOG Nelson Farms 1-24H (now operated by Hess) and were subsequently involved in the acquisition and development of over 300,000 acres.

For North Dakota, what an important opportunity to add value to the production of oil and gas; helping economics for producers, mitigating the environmental impact of oilfield waste water, and creating new business opportunities for the state.

Best wishes to you and everyone involved in this project!

Sincerely,

J Powers

James E. Powers, Partner
Powers Energy Corporation

Triple 8, LLC

4958 141st Ave NW
Williston, ND 58801

2/14/2018

Scott F. Korom, PhD, PE
Senior Environmental Engineer
Barr Engineering Co.
234 West Century Avenue
Bismarck, ND 58503
SKorom@barr.com
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RE: Support for proposal entitled "Oilfield produced water purification with chemicals production and valuable metals recovery" submitted to: North Dakota Oil & Gas Research Program – North Dakota Industrial Commission.

Dear Dr. Korom,

Triple 8 LLC is pleased to provide this letter of support for the UND team's project investigating a novel method for recovery of solids and high-value elements from high total dissolved solids (TDS) oilfield brines and produced waters. We believe that the technology will drastically reduce the cost or quantity of energy required to evaporate the water, allowing recovery of the dried solids. We also understand that the targets for this project include high value lithium and rare earth elements, as well as other minerals that can be sold to market. The markets and price projections for these products appear very favorable both in the near-term and long-term.

Triple 8 LLC learned of this potential business opportunity back in the spring of 2016. After some preliminary research that indicated very promising markets for the targeted products, as well as inherent advantages of utilizing a waste stream as the feedstock, approached the UND team to help develop the technical aspects. UND completed the first year's research which included preliminary plant design as well as economic feasibility. A parallel effort, Triple 8 LLC worked with the UND Chemical Engineering Department senior plant design class, in which a group of students performed a conceptual design and associated broad cost economic assessment of recovering high value elements from oilfield wastewaters. We have formed a lasting and valued partnership with UND and look forward to the next stage of research that needs to be completed.

Based on the tremendous interest thus far, and the positive discussions and promising potential of the proposed UND technology, Triple 8 LLC is now molding itself into a Consulting as well as Research and Development company with a keen interest in recovering high value elements from oilfield wastewaters. While we are partnered with UND to complete the necessary research for recovering high-value elements from oilfield brines and produced water, we have also engaged Barr Engineering to complete a feasibility study to provide validity to the economics behind the concept.

Triple 8 LLC is also partnering with Dr. Rostron is a hydro-geologist and has been researching produced water from the Williston Basin since 1996. Dr. Rostron has fully characterized water samples from over 2000 wells in the basin and will be providing data necessary to localize areas of interest for recovering high value rare earth minerals from the produced water.

Here are the hours and wage summary information for this year's work.

	Hours worked (annualized)	Hourly Wage	Total wages
Carla Kemp	208	80	$16,640
Steve Kemp	208	80	$16,640
Totals	416		$33,280

Trip	Number of Trips	Total Miles
Grand Forks	2	1368
Bismarck	2	892
Edmonton, AB Canada	1	1354
Totals	5	3614
	Cost of mileage @ $0.575	$2078.05
Hotel Stays	5 total nights @ $83.70/night	$418.50
Total Cost of In-kind	Total time/mileage/hotel	$35,776.55

We are anticipating an average of 4 hours per week dedicated to working on the project. However, we will break this down further for specific travel and other hours as anticipated. There will be at least 2 trips to Grand Forks to meet with you, at least two trips to Bismarck to meet with Barr Engineering and one trip to Edmonton, AB to meet with Dr. Ben Rostron.

Trips to Grand Forks will be 10 hours of travel each trip, along with 4 hours onsite working with you or other staff at UND. Total hours for trips to Grand Forks will be 56 hours between Carla and I.

Trips to Bismarck for meetings with Barr Engineering we anticipate 7 hours round trip to Bismarck, along with 2 hours onsite working per trip. Total hours for trips to Bismarck will be 36 hours between Carla and I.
We will also be making one trip to Edmonton Alberta to meet with Dr. Ben Rostron. The trip to Edmonton will be 22 hours round trip for travel, and 4 hours onsite. Total hours for trip to Edmonton will be 52 hours. After all travel we are leaving ourselves with an average of 2.65 hours for Carla and I per week to work on the project which is a very conservative number considering the work that needs to be done.

Respectfully,

Steve Kemp and Carla Kemp
Owners
Triple 8, LLC

UNIVERSITY OF UND NORTH DAKOTA

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Dr. Scott Korom
Barr Engineering Company
234 W Century, Ave
Bismarck, ND 58503

RE: Support of Barr Engineering's proposal entitled "Conceptual design for chlor-alkali and valuable materials production from oilfield brine," submitted in response to the special grant round for the Oil & Gas Research Program of the North Dakota Industrial Commission.

Dear Dr. Korom,

The University of North Dakota Institute for Energy Studies (IES) is pleased to provide support to the Barr Engineering team to develop the design and evaluate the economics of a commercial facility to produce chlor-alkali chemicals and other valuable materials from oilfield brine. IES has been engaged with project co-sponsor Triple 8 LLC for about the last 15 months in development of these concepts. We started by working with a UND chemical engineering design group to evaluate the feasibility of using waste heat generated at power plants located within oil production in the Williston Basin to produce distilled water and a dry mixed salt that could be further processed to produce chemicals or recover valuable metals. This initial study showed promising results, and prompted further development efforts.

In conjunction with Triple 8 LLC, the IES decided it was prudent to contract the services of a qualified Engineering Firm. IES has worked with Barr Engineering on multiple similar projects in the past, as well as currently and encouraged Triple 8 LLC to engage with Barr to further develop the commercial design concepts. In partnership with Barr Engineering and Triple 8 LLC, the IES submitted a proposal to the November 1, 2017 Oil & Gas Research Program grant round. The reviews of the proposal were generally positive, but brought up some significant questions that needed to be answered and addressed. Based on the reviews, we decided to pull the proposal from consideration to give ourselves the opportunity to address the important questions raised by the technical reviewers. Subsequent to that proposal, Triple 8 LLC contracted Barr Engineering to initiate a technology screening assessment to further develop the plant design. Based on the new information developed and the previous proposal's reviews, we have decided that the most logical course of action is for Barr to take the lead on the next phases of development, including the scope of work proposed for this project.

To support the proposed project, the IES will provide the following scope of work.

- Laboratory testing of methods to purify the oilfield brine. The testing will involve methods to separate divalent cations as well as fractional crystallization tests. This testing will be based on the approaches currently used for commercial lithium production using solar evaporation ponds. We expect that using a fractional crystallization approach that takes advantage of relatively solubility differences of the various cations in the brine, that we can generate salt fractions that are enriched in sodium chloride and lithium, and potentially other valuable elements/minerals. The sodium chloride-enriched salt fraction can more effectively be used as the feed for the chlor-alkali process, as it will require less purification prior to use. For lithium, the goal is to generate a concentration sufficient to warrant additional processing for purification into battery grade lithium carbonate. The salt fractions generated will also be analyzed to determine the partitioning of other potentially valuable elements/minerals, such as magnesium, bromine and iodine. IES will work with the Barr team to identify the potentially salable elements/minerals in the brine.
- To support the Barr Engineering team's plant design, the IES will provide Aspen Plus® process modeling to help determine material and energy balances and size process equipment. IES will work directly with Barr Engineering to assist in generation of process flow and piping & instrumentation diagrams. The IES will also support the Barr team with estimation of the process economics.
- The IES will prepare reports and required deliverables as dictated by the Research Agreement between UND and Barr, as well as support the project reporting requirements of the Research Agreement between Barr and the NDIC.

The IES is excited to continue its partnership with Barr Engineering and Triple 8 LLC in development of these concepts. New methods of dealing with produced oilfield brines are required for sustainable development of North Dakota's tremendous oil & gas reserves. We believe the proposed technology has tremendous potential to provide not only a solution to this challenge, but also significant revenue generating opportunity. Local manufacturing of the chlor-alkali chemicals will provide the high-volume local markets with significant reductions in transport costs, and the plant also has the potential to be a significant exporter of products to create new revenues for the state and local economies.

Dr. Daniel Laudal will be the project manager for the IES team and will be supported by technical leads Dr. Kirtipal Barse and Dr. Xiaodong Hou, who will lead the Aspen modeling and salts purification tasks, respectively. The resumes of the key personnel for UND are attached with this letter. The total budget for IES' scope of work is $50,000, which is detailed in the attached budget justification. We wish the Barr team success in this proposal effort, and look forward to continuing our collaborations.

Sincerely,

Michael D. Mann

Dr. Michael D. Mann
Executive Director
Institute for Energy Studies
University of North Dakota

Dr. Barry Milavetz
Assoc. VP for Research
& Economic Development
University of North Dakota

Budget Justification

University of North Dakota Institute for Energy Studies

Labor:

The key personnel on the project are Drs. Laudal, Barse and Hou. Each has management and technical roles that are defined in the attached letter of support. A graduate student will support the project by performing the majority of the experimental work with guidance from the project leads. The following is a breakdown of the labor costs associated with completion of the scope of work.

Note that hours of labor are only used for proposal purposes. The University tracks employee's time on projects on the basis of effort. Actual salary for specific personnel have been used, and average salary for generic labor categories have been used.

Category	**Hours**	**Rate**	**Total Cost**
Laudal	80	40.87	3,270
Barse	100	34.77	3,477
Hou	100	28.52	2,852
Graduate Student	397	21.15	8,393
Administrative	20	22.00	440
TOTAL			**18,431**

Fringe Benefits:

Fringe benefits have been estimated based upon historical averages. For staff, an average of 40% of salary has been used. For the graduate student an average of 5% of salary has been used. These estimates are used only for proposal purposes. Upon award, only the true costs of each employee's fringe benefits package will be charged to the project. Based on these estimates, the total fringe benefits requested is $4,435.

Supplies:

Supplies costs of $5,000 are requested which is an estimate based on previous experience and the scope of work. Supplies for laboratory testing, such as glassware, filters, sample storage, and reagents will be required. Additionally, project reporting costs such as paper, folders, logbooks…etc have been estimated and included. Additionally, based upon the estimated usage on the project, we are requesting partial support of the IES' Aspen Plus software license. This partial support has been estimated at 25% of the annual license cost, or $500.

Analytical:

To support the laboratory testing in the project, analytical testing is required. We anticipate the following breakdown. The costs for each type of analysis are based on the standard rates for the UND Materials Characterization Laboratory.

Analytical	#	Rate	Total
XRD, XRF, SEM	35	103	3,605
ICP-MS	10	300	3,000
Sample Prep	20	75	1,500
Total			**8,105**

XRD: X-ray diffraction
XRF: X-ray fluorescence
SEM: Scanning electron microscopy
ICP-MS: Inductively coupled plasma – mass spectrometry

Indirect Costs:

UND uses the modified total direct cost method, which is defined as the total direct costs minus equipment expenditures exceeding $5,000 and subcontracts in excess of the first $25,000. For this proposal, the federally negotiated rate of 39% has been used. Total indirect costs requested are $14,029.

Budget Summary:

The table below breaks down the major budget categories.

Category	Cost
Salaries	18,431
Fringe Benefits	4,435
Total Labor	22,866
Supplies	5,000
Analytical	8,105
Total Direct Costs	35,971
Indirect Costs	14,029
Total Project Cost	**50,000**

Creedence Energy Services
PO BOX 3480
Minot, ND 58702

February 14, 2018

To: Scott F. Korom, PhD, PE
Senior Environmental Engineer
Barr Engineering Co.
234 West Century Avenue
Bismarck, ND 58503

RE: Support Letter for proposal entitled "Oilfield produced water purification with chemicals production and valuable metal recovery" submitted to: North Dakota Oil and Gas Research Program – North Dakota Industrial Commission.

Dear Mr. Scott F Korom,

Creedence Energy Services is pleased to provide a letter of support for the proposal entitled "Oilfield produced water purification with chemicals production and valuable metal recovery". Creedence recognizes the value this project and operation will provide to market produced commodity chemicals and ultimately lithium recovery.

We understand the chemical commodity market and the value it will add to the energy services company's supply chain having a manufacturing plant based in North Dakota in addition to the jobs it will provide. We also understand the rare earth mineral lithium demand in the market as it continues to focus on upgrading battery technology.

Creedence Energy Services is an oil and gas production chemical and acidizing company headquartered in Minot, ND with operations based out of Williston, ND.

We support and wish the team success in the proposal effort and look forward to the opportunities this will provide.

Regards,

Wyatt J. Black

Wyatt J Black
Vice President
Creedence Energy Services