Transmittal Letter

May 30, 2017

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

Dear Ms. Fine:

Subject: UND Proposal Entitled "*Development of Testing Methods and Design of Inorganic Scale Treatments in Williston Basin, North Dakota*" for a North Dakota Industrial Commission Oil and Gas Research Program Funding Request.

A UND Research Team led by Dr. Hadi Jabbari and Dr. Minou Rabiei is proposing a project to develop new and more-effective chemicals to mitigate the problem of inorganic-scale deposition in Williston Basin, Bakken Formation wells. Successful completion of this research project can result in improving production decline-rates which leads to less need for workover jobs and great impacts on the oil industry, economy, and environment in North Dakota.

Enclosed please find an original and one copy of the subject proposal along with a check for the $100 application fee.

Should you have any questions, please feel free to contact me at hadi.jabbari@engr.und.edu and/or *701-777-3867*.

Sincerely Yours,

Hadi Jabbari, Ph.D.
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Dr. Barry Milavetz,
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Oil and Gas Research Program

North Dakota

Industrial Commission

Application

Project Title: Development of Testing Methods and Design of Inorganic Scale Treatments in Williston Basin, North Dakota

Applicant:
Department of Petroleum Engineering, University of North Dakota

Principal Investigator: Dr. Hadi Jabbari

Date of Application: Jun 1, 2017

Amount of Request: $435,433.23

Total Amount of Proposed Project:

$1,060,205.60

Duration of Project: 36 months

Point of Contact (POC): Dr. Hadi Jabbari

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ABSTRACT

Objective:

The hydraulic fracturing operations in the Bakken Formation, Williston Basin, ND has been very successful during the recent decades. However, the scale deposition – mineral deposits forming on the surfaces of production system and in the bottomhole around wells – is reported to be one of the major issues in production from wells drilled in the Bakken Formation. It has been estimated that the scale impact on reservoirs in North and South America is as high as $600 million each year. Improved scale inhibition and treatment materials can result in increased operational efficiency as well as optimized treatment procedures with higher success rates. A primary objective in this proposed work is to develop more-effective chemicals and improved treatment techniques to tackle the scale deposition problem in the Williston Basin, ND.

There are scale inhibition/treatment methods currently available in the industry. However, these treatment methods and chemicals are sometimes inefficient because scale inhibition/treatment is, in fact, case-sensitive where the response from it varies throughout the Williston Basin and from well to well. The responses could be different in terms of type of inhibition and treatment materials, remedial operations, timing of the treatment, and thus handling of the cost.

The main goals of this proposed research are twofold:

- Conduct a comprehensive study on the inorganic-scale formation in the Williston Basin through field testing, simulation/modeling, and laboratory work.
- Designing and formulating more-effective chemicals to inhibit and/or delay the scale deposition process through the Williston Basin with various ranges of parameters.
- Assess the business potential for new, more-effective chemicals and treatment techniques that can outperform current practices in mitigating the scale problem in the Williston Basin.

Expected Results:

This project is expected to achieve the following results:

- A summary report of current scale inhibition/treatment operations in the Williston Basin will be prepared.
- Investigating the current scale inhibition/treatment operations, we will investigate the potential for improvement of current materials used for scale inhibition and formulate more-effective chemicals and application techniques for Williston Basin wells.
- Determine and establish links between significant parameters in hydraulic fracturing, production operations, and well/reservoir conditions, which are contributing to scale deposition. We will collect the available data through various sources including our industry partner (i.e. ***Creedence Energy Services LLC***) and the NDIC website to produce data bases used in this research.
- Conducting field tests and implementing the developed chemicals and technology from this project in the Williston Basin wells facilitated through our industry partner, ***Creedence Energy Services LLC***. This is a great opportunity since we can observe and report the performance of modified chemicals in the active wells producing from the Bakken Formation; an opportunity that may not be available to many researchers.
- Improve scale prediction models through lab experiments and simulation. More accurate scaling simulation models will be created by calibrating models through sensitivity analysis, lab testing, and interpreting field test data.
- Successful completion of this project can lead to less maintenance cost in Bakken wells which means less fresh water usage and less amount of liquid waste product; a key outcome with positive environmental impacts in the State of North Dakota.
- Commercialization of more-effective scale inhibitors and treatment materials in Williston Basin wells; the downturn in industry during the past two years (owing to low oil prices) has caused an industry-wide focus on the maintenance of currently producing wells (i.e. to avoid/inhibit scale deposits) rather than drilling and completion.

Duration:

The duration of the proposed project will be 36 months (from 10/01/2017 to 09/30/2020).

Total Project Cost:

The total cost of the project is $1,060,205.60. The amount requested from the NDIC-OGRC is $435,433.23. UND will provide $288,772.37 in the form of contributed salary, and our industry partner— ***Creedence Energy Services LLC***.— will provide $336,000.00 as cost-share towards the project.

Participants:

A UND research team of two faculty members, one postdoc, and two graduate students from the department of Petroleum Engineering will participate in this project. ***Creedence Energy*** is our major industry support in this project and ***BARR Engineering Co.*** will provide their expertise in the water analysis task where we acquire water samples and determine their composition and characteristics from a large number of Williston Basin wells.

PROJECT DESCRIPTION

Objectives:

The Williston Basin, located primarily in Western North Dakota and parts of South Dakota, Montana and Canada, was estimated to contain 7.4 billion barrels of oil, 6.7 trillion cubic feet of associated gas and 0.53 billion barrels of natural gas liquids (NGLs) by the US Geological Survey [*USGS*, 2013]. With current oil production at almost 1,000,000 barrels of oil per day (BOPD), the rapid growth in oil production has resulted in the growth of associated maintenance problems. Production challenges in Bakken-Three Forks wells include scale, salt, paraffin, corrosion and sand. However, scale is considered the worst of them all. The Bakken Formation is approximately 10,000 ft deep with a bottom-hole temperature ~220-240°F.

Pump failures, production losses, and well shutdowns all can result from scale buildup. In the Williston Basin it pays to prevent scale deposition from day one. The University of North Dakota, Petroleum Engineering Department, in conjunction with ***Creedence Energy Services LLC*** (PSP:

private sector partner) is proposing to conduct a comprehensive study on the scaling problem in the Williston Basin and seek technological improvements to formulate chemicals that can provide beneficial and cost-effective treatment methods for handling the problem. The overall objective of the proposed work is to perform proof-of-concept testing of more-effective scale inhibitors and to undertake preliminary development of the business model and venture structure for more-effective products, which can outperform the chemicals currently used in North Dakota.

In this research project, we propose studying the significant aspects of inorganic-scale formation in Williston Basin wells through modeling and simulation, lab experiments, and data-mining methods. We will also conduct a market analysis for new inhibitors and chemicals where our industry partner will be a great asset in this task since they are currently very active in the scale inhibition/removal business in the Williston Basin.

The idea of conducting this research was discussed with a few members of the Industry Advisory Council (IAC) of the Petroleum Engineering Department (PE) at the University of ND (UND). Those members supported the proposal and recognized the benefit to the oil industry in ND (supporting letters from the industry partners are attached).

Methodology:

In order for any technology to successfully inhibit, remove, or mitigate the scaling problem in the Williston Basin, it should be: a) case-based, b) robust, and c) provide the optimum net present value and low-cost operations. In this work, we will address these aspects through a comprehensive study including lab work, modeling/simulation, and data-mining techniques. The main outcomes resulting from this work will include more-effective inhibition and treatment materials as well as optimal operational strategies (e.g. minimum effective concentration, MEC, application techniques, etc.).

The main driving force in this proposed work is the high demand in North Dakota oil & gas industry for more-effective solutions to the scaling problem in the Williston Basin. In this research, we propose to investigate the significant aspects and parameters contributing to the scaling problem and

conduct a comprehensive study to pinpoint the operational and geochemical causes of the scaling problems so that proper remedial actions can be designed.

To fulfil our objectives in this work we propose to conduct these tasks as follows:

- Water analysis to determine composition and characteristics of different minerals in wells
- Scale characterization
- Reservoir rock characterization
- Scaling tendency in the Williston Basin
- Data visualization for business intelligence
- Molecular dynamics simulation (MDS) for better understanding of scaling mechanisms
- Lab experiments to formulate more-effective chemicals and compare application techniques, such as continuous addition, squeeze, multiple function treatments.
- Evaluating the success of inhibition/treatment by monitoring the process in the lab and simulating the scale formation process using commercial simulators.
- Data-mining to make logical relationships among the significant parameters and controlling factors.

Task 1— Water Analysis

Conducting a thorough water analysis over the Williston Basin is extremely crucial to the success of this study and the potential outcomes. Our industry partner (***Creedence Energy Services LLC***) will facilitate acquiring water samples from many wells in the Bakken Formation, especially from the fields where they experienced higher rates of scale formation and higher production decline. The water samples will be taken to the Environmental Analytical Research Laboratory (EARL) located at UND to obtain the water composition and characteristics. **Appendix D** provides the list of water analysis laboratory facilities at UND. In the water analysis task, the followings will be conducted:

- **Aqueous Anions via Ion Chromatography:** Routine analyses items include F^-, Cl^-, Br^-, NO_2^-, NO_3^-, SO_4^{2-} and PO_4^{3-}.
- **Aqueous Cations via Flame AAS (Atomic Absorption Spectrometry):** The EARL currently has lamps for analyzing K, Na, Li, Ca, Mg, Fe, Cu, Ni, Mn, As, Se, Sb, Hg, Zn, Cd and Pb.
- **Sulfide Analyses:** Sulfide analyses in sediment via Chromium Reduction Method.

- **Sulfur Analysis (Total sulfur or Organic sulfur):** Sulfur analyses via LECO SC-432DR Sulfur Analyzer installed at the EARL laboratory at UND.

These data will be used to formulate proper chemicals for scale treatments in the lab as well as running scale simulation models. This task will be performed with the collaboration of ***BARR Engineering Co.*** who will provide their expertise in water analysis and environmental analytical research.

Task 2— Scale Characterization to Determine Type and Compositions

To design an inhibition scheme and removal treatment, it is necessary to collect as much information as possible on the chemical and physical characteristics of the fouling scale deposits. Ideally, we need to know the chemical composition of the scales as well as the amount and location of where they are formed. A good understanding of the type and location of deposited scale within the well or near wellbore region are critical for designing effective inhibitors and/or dissolvers. We propose to obtain representative samples of the scales from Bakken wells to conduct the compositional analysis. ***Creedence Energy Services LLC*** will provide us with enough scale samples from Bakken wells for laboratory study and characterizations.

In order to give a quantitative assessment of the elemental composition of scale samples we will conduct x-ray analysis on the solids using X-ray powder diffraction (XRD), X-ray fluorescence (XRF), nuclear magnetic resonance (NMR), and scanning electron microscopy (SEM) equipment installed at the UND, Advanced Petroleum Engineering Laboratory (APEL) (**Figures 1** and **2**). This type of analysis can give us an identification of the specific crystalline minerals in the scale samples. All these data will be utilized in a data-mining platform and converted into meaningful and comprehensible information (e.g. the tendency of scale and evaluation of inhibition/treatment techniques in a specified area in the Williston Basin). It will also help us to formulate chemicals for the inhibition and treatment of scale deposition to be tested in the lab.

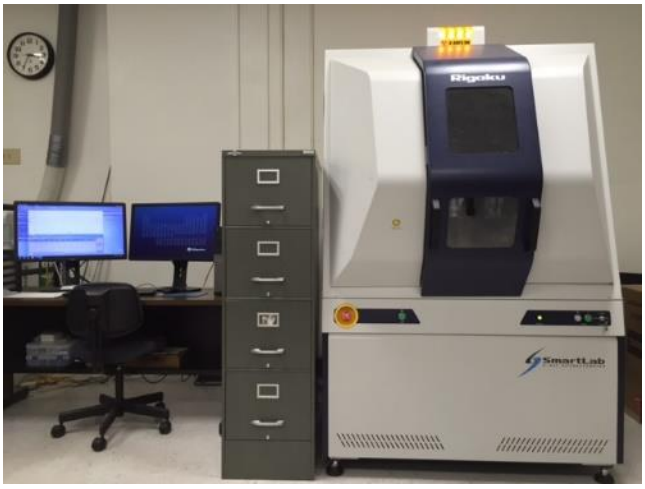

Figure 1: XRD analyzer installed at the UND, Advanced Petroleum Engineering Laboratory (APEL)

Figure 2: XRF analyzer installed at the UND, Advanced Petroleum Engineering Laboratory (APEL)

Task 3— Reservoir Rock Characterization

To formulate effective chemicals for inhibition and treatment of inorganic scale deposits in the Williston Basin, we will characterize rock and fluids and investigate their interactions in the system. In order to characterize reservoir rocks, we take rock samples from selected Bakken wells and acquire petrophysical, transport, geochemical, and elemental data using XRF, XRD, NMR, and Scanning SEM measurements (conducted at the UND, Advanced Analytical Characterization lab) (see **Figures 3** and **4**).

These data will be used in the simulation of scale formation and help us interpret the data we collect from coreflood experiments that altogether provide the prediction of scaling and formation damage around the wells under the different scenarios of well, reservoir, and inhibition conditions.

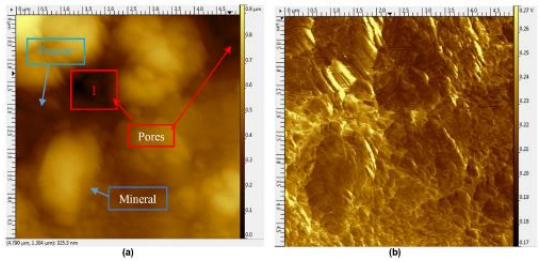

Figure 3: Atomic Force Microscopy images of Bakken samples [*Liu et al.,* 2016]

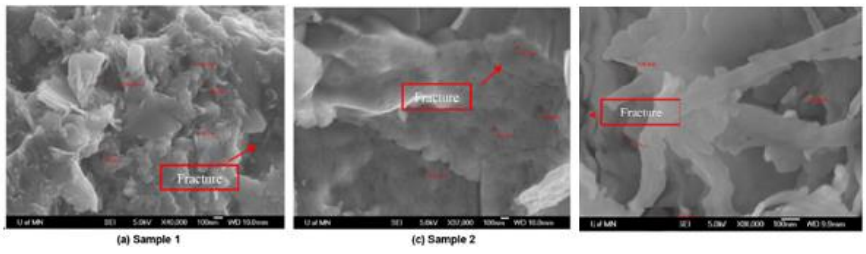

Figure 4: Pore-structure analysis for Bakken samples using FE-SEM [*Liu et al.,* 2016]

Task 4— Scaling Index (SI) and Data Visualization

Scaling potential indices have been developed to predict the likelihood of calcium carbonate precipitation; such as the Langelier Saturation Index [1936] and Stiff-Davis Stability Index [1952], which have been used in industry. However, neither indices were developed for the highly saline conditions that exist in the Williston Basin, ND. The precipitation potential of calcite increases, that is, calcite solubility decreases, with decreasing pressure, increasing temperature, and increasing concentrations of calcium, alkalinity, and pH. Furthermore, for given concentrations of calcium, alkalinity, and pH, calcite solubility decreases with decreasing solution ionic strength. In this research, we will compare these parameters to locations and formations in the Williston Basin where scaling problems exist so that predictive scale models can be developed. In addition, guidelines may be developed to assist on well design, hydraulic fracturing design, development, and operation.

As a preliminary study, we have performed geographical analysis of Stiff-Davis scale-tendency index for dozens of Bakken wells to present data visualization that can help us correlate the scale tendency with significant parameters in the Williston Basin (See **Figure 5**). This provides a quick overview of the scale problem versus location and other factors over the Williston Basin. On the map, the scaling problem is more severe where the circles are darker (in red) in hue and bigger in size.

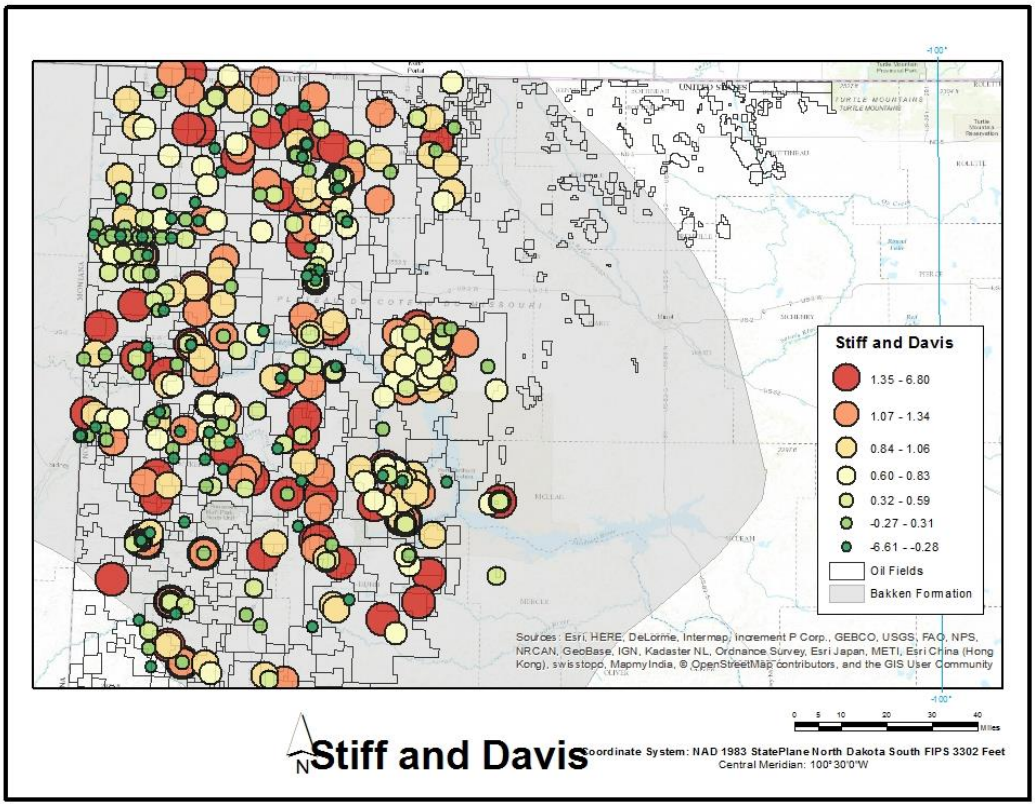

Figure 5: Geographical representation of scaling tendencies of Williston Basin [*Jabbari et al*, 2016]

Task 5— Inorganic Scale Mechanism: MDS and Conventional Reservoir Simulation

It has been reported that the scale formation is more likely during the first two years of production history and/or the first 20,000 bbls of produced water in Bakken wells [Cenegy et al., 2011]. Since this is just an approximation for such an important parameter as the time of scale formation, we propose to conduct both molecular dynamic simulation (MDS) and conventional reservoir simulation for better understanding of the scaling mechanism in the well, within the near wellbore region so that we better estimate the time of super-saturation right before scales form. Then, we can relate the scale-formation timing to significant factors which contribute to future planning, such as in hydraulic fracturing jobs, etc. Scale-formation mechanisms have been investigated thoroughly by many researchers [Crabtree et al., 1999; Nancolas et al., 2007].

Although the driving force for scale formation may be a temperature or pressure change, outgassing, a pH shift, or contact with produced water (that has become oversaturated and scale-prone) do not always produce scale. **Figure 6** shows the process of scale formation where we can see for a scale

to form, it must grow from solution. Scaling starts if unstable clusters of atoms form in a saturated fluid (see homogeneous nucleation and heterogeneous nucleation in **Figure 6**). The method proposed seeks to better describe these phenomena is molecular dynamics simulation (MDS) which we propose to conduct in Williston Basin wells. The outcome from this task will be determination of time-to-scale as well as the rate of scaling under different well/reservoir/operational scenarios.

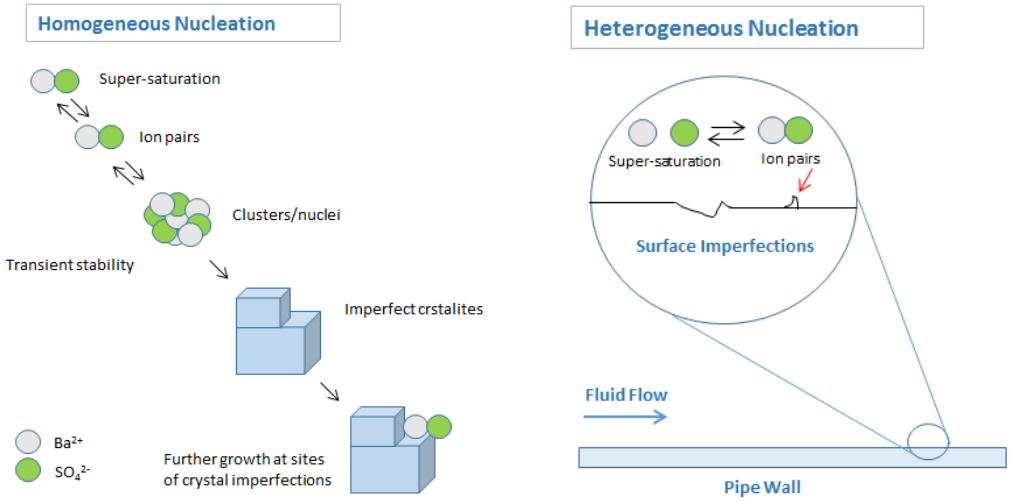

Figure 6: Process of scale formation from molecular perspective [*courtesy of Schlumberger*]

Task 6— Experimental Study: Coreflood Testing and Developing Material Selection Protocols

After data gathering and running different types of analyses explained above, we will conduct various experiments at the UND, Advanced Petroleum Engineering Laboratory (APEL) to determine:

a) Best inhibitors required for particular mineral-scale and specific water compositions
b) Minimum effective concentration (MEC) to maintain inhibition under any conditions
c) Concentrations still available in the fluids
d) Mechanism of actions of each scale inhibitor and formulate optimal chemicals

Task 6.1 Rank Various Inhibitors vs. Temperature

Since temperature has major effect on the growth of mineral crystals and nucleation process, we will utilize a jar-test setup to study the ability of formulated chemicals at different temperature to prevent precipitation of common scales formed in Bakken wells, e.g. Carbonate Calcium, Barium Sulfate, etc. **Figure 7** shows such a setup, which is usually the first-stage test to evaluate scale formation and

compatibility of two waters, namely water-based fracturing fluid and formation water used in hydraulic fracturing jobs.

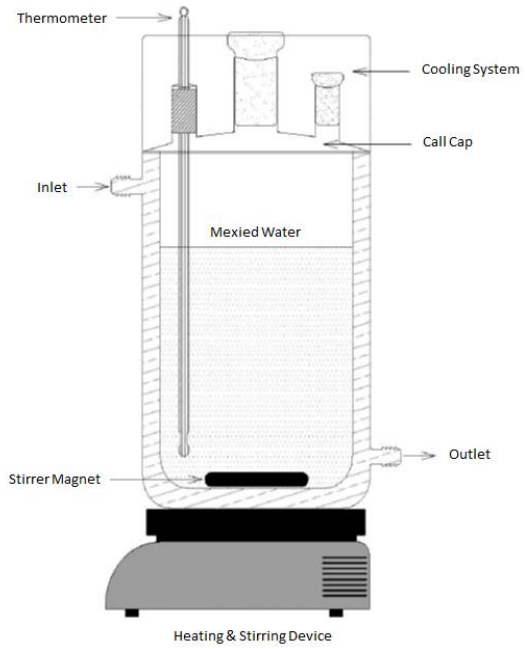

Figure 7: Atmospheric scaling test setup

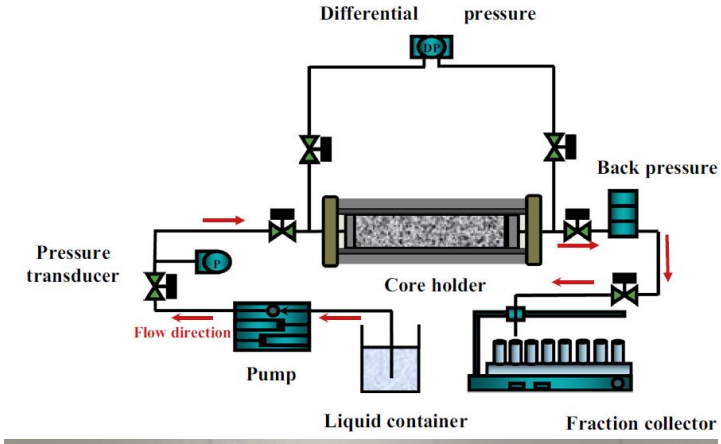

Figure 8: Coreflood tester installed at the UND, Advanced Petroleum Engineering Laboratory (APEL)

Task 6.2 Coreflood Testing

Coreflood tests— with using core plug samples from Williston Basin wells— provide best simulation available of the near wellbore and reservoir conditions. See **Figure 8** for the coreflood equipment installed at the UND, Advanced Petroleum Engineering Laboratory (APEL), which includes a containment chamber, heater, pumps, regulators, and fraction collectors. The coreflood tests in this task will allow us to determine adsorption/desorption isotherms required for modeling inhibitor lifetimes and their effects on reservoir rocks, which are very valuable information for comparing the effectiveness of different chemicals and leads to formulating best chemicals suitable for the well, reservoir, and fluids conditions in the Williston Basin. It also facilitates testing the impact of significant

parameters on the scaling process, such as: temperature, pH, application concentrations and compositions.

In this task by conducting several coreflood experiments, we will also look into formation damage and permeability impairment from scale deposition and correlate it with the common high decline rates in Williston Basin, Bakken Formation wells. **Appendix B** provides the list of the chemicals to be investigated in this work to compare their performance in inhibition and treatment of scale deposition under the various conditions of well, reservoir, and fluids in the Williston Basin, which can lead to formulating more-effective chemicals and designing improved treatment techniques.

Task 7— Data Mining: State-of-the-Art Data Management

There exist industry-standard modeling packages available today, including "*Place It"* from Scale Solution, "*ScaleSoftPitze"*, and *"Squeeze"* from Heriot Wat [*Starkler et al.*, 2012; *Sorbie,* 2012; *Cook et al.*, 2015]. However, the biggest challenge confronting the industry is improving the modeling accuracy since the non-uniqueness in input data usually prevents accurate determination of scaling tendency, and thus hinders optimal decision making. Furthermore, these models were not based on the geochemical compositions of the produced waters in the Williston Basin with high TDS (total dissolved solids) and salinity.

We propose to meet these challenges by incorporating data-mining techniques to combine data from multiple sources (data collection, modeling/simulation, and laboratory work) to achieve improved accuracy in scale-formation prediction in the Williston Basin, and thus better inferences used later on in the assessment phases of the problem (data-fusion technique).

For this, advanced data-fusion methods will be utilized to analyze the large amount of data collected from all tasks including: lab data, simulation results, and field data in order to uncover the main signatures that may be culprit for potential scale formation in the Williston Basin, ND. Many factors control the state of scaling in the Williston Basin, and hence proper selection of scale inhibition and planning for treatments are still challenging in the North Dakota oil industry.

A successful scale handling requires the analysis of a large amount of data, which is often ignored in the Bakken oil industry due to lack of time and more importantly lack of appropriate tools, procedures, and/or knowledge. Therefore, this proposed work aims at filling these gaps and make a bridge between industry and academia to advise improved solutions for the scaling problem in the Williston Basin, North Dakota.

Task 7.1 Post-Mortem Analysis on Failed Wells

Conducting a post-mortem analysis on the failed wells in the Williston Basin, we can determine a predictive pattern in the collected data through data-mining techniques. Factors considered for the data-mining portion in this proposed work include, but are not limited to:

- Well location (X,Y; Easting, Northing)
- Cumulative water production from initial production to failure
- Time since initial production and time to scale formation, etc.
- Down-hole pumps parameters (e.g. in-take pressure, materials, operator, vendor, etc.)
- Geology and mineralogy of the reservoir (SEM, elemental analysis: XRD, XRF)
- Hydraulic fracturing method (scour or multistage)
- Hydraulic fracturing parameters; frack-fluid type, proppant type, chemical additives, etc.
- Review of formation water analysis and frack fluid compositions
- Map of scale tendency over the Williston Basin (e.g. Stiff-Davis Index)
- Type of inhibition materials used in the wells
- Various methods employed for applying inhibitors in the Williston Basin; continuous or squeeze
- Residual scale inhibitor measured in produced fluids

Anticipated Results:

This research work will provide a comprehensive overview of the science and technology of inorganic scale formation and inhibition in the Williston Basin with emphasis on basic principles of chemical, environmental, inhibition, data-mining as well as operations. We will investigate several aspects of inorganic scales, including: a) chemical and physical aspects of scale formation, b) different inhibition options available to the industry, and c) the mathematical methods behind

engineering guidelines. This work will provide a discussion of best practices for control of inorganic scales in North Dakota from the following perspectives:

- Better understand the scaling problem in the Williston Basin as there is no similar comprehensive study conducted so far in the Williston Basin.
- Evaluate different solution options and formulate more-effective chemicals to tackle the scaling problem in the Williston Basin.
- Investigate and compare different control procedures, which have been practiced in the Williston Basin and design optimized application techniques.
- Evaluate overall results from lab experiments, simulation, and data-mining and validate/compare with the results from field tests to be conducted with the help of our industry partner, ***Creedence Energy Services LLC***.

Figure 9 describes the stages of this proposed research to collect data, acquire data from different analyses, design and formulate optimal chemicals, and implement the developed technology in Williston Basin wells. The field tests will be facilitated through our PSP (***Creedence Energy Services LLC***) followed by preliminary development of the business model and venture structure for new products. In this project, we will also take advantage of the feedback and comments that we receive constantly from industry.

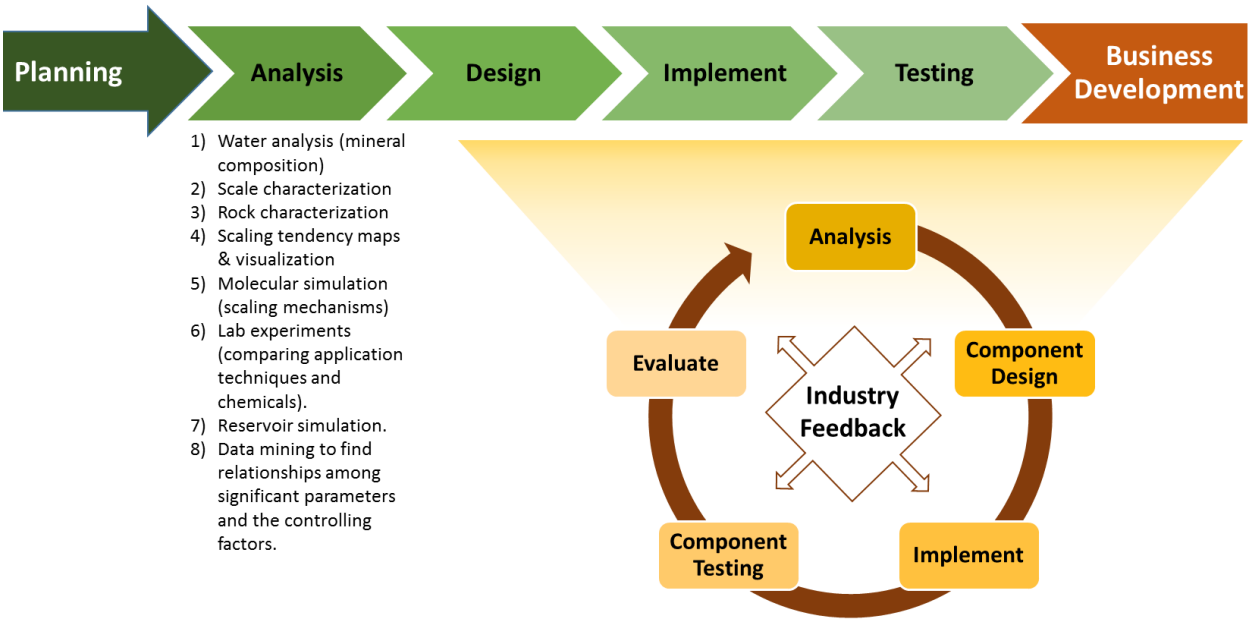

Figure 9. Key stages of this proposed research

Facilities and Resources:

The research team has access to the state-of-art facilities both internal (at UND) and external (at industry partners location) to perform the proposed research. Details of laboratory facilities available to us at UND are shown in **Appendix D**.

Environmental and Economic Impacts while Project is Underway:

No negative environmental impacts seem to occur while the project is underway. On the contrary, there are positive economic and environmental impacts that can be resulted from this project, which are described below.

Ultimate Technological and Economic Impacts:

Scale deposits are common in Bakken/Three Forks wells which are hydraulically fractured and are producing high water-cut where calcium-carbonate and iron-carbonate scaling pose a threat to productivity. Such deposits can coat perforations, casing, tubing, valves, pumps, and downhole completion equipment (see **Figure 10**). If it is not prevented or removed, scale deposits will adversely affect production leading to eventual abandonment of wells and thus loss of tremendous investments.

Figure 10. Tubing fouled with calcium-carbonate scale [*Courtesy of Schlumberger, 2017*]

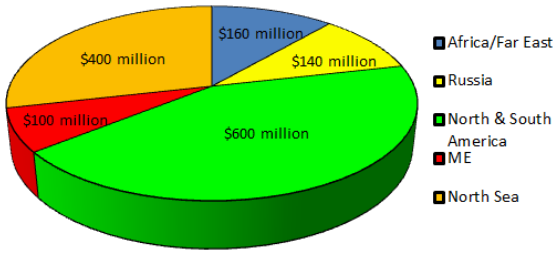

Figure 11. Total estimate of worldwide scale costs at $1.4 billion [*Courtesy of Frenier and Ziauddin,* 2008]

This proposed work seeks for improved scale remedial program and more-effective chemicals through detailed studies and technological improvements, which can eventually be commercialized with positive impacts on the state of North Dakota in a number of ways as follows:

I. Economic Impact to the State of North Dakota:

The economic impact of scale on oil industry worldwide has been estimated at more than $1.4 billion each year [*Frenier and Ziauddin*, 2008]. For example, **Figure 11** shows an estimate that the adverse economic impact of scale problem on reservoirs in North and South America is as high as $600 million each year. Therefore, with over 10,000 wells currently producing from the Williston Basin, ND and with the daily oil production almost around 1 million barrel (through December 2016), there is a *big market need* for *improved scale inhibition and treatment materials as well as for optimal treatments* in Bakken wells with a high potential of scale deposition. Our industry partner Creedence Energy Services LLC, as mentioned in their letter of commitment, has also pronounced the need for more-effective scaling prevention.

II. Benefit to PSP

This research will benefit the private sector partner (PSP, ***Creedence Energy***) by: a) providing more insights into the scaling problem in their producing wells, b) generating databases of gathered and acquired data for them to use in future studies, and c) designing and producing improved scale inhibition and treatment materials to mitigate such a problem in the Williston Basin.

The research will also help other chemical service companies gain further insight into the scale formation process specific to Bakken/Three Forks wells, including the type of scale likely to form based on brine composition, wellbore dynamics, hydraulic fracturing schemes, etc. Ultimately, this research will help to reduce the extraordinary cost of scale remediation to operators by providing a more robust and scientific approach to: a) diagnosing a well's susceptibility to scale deposition, and b) designing the most effective scale inhibitor chemistry and application technique.

III. Impact on Private Sector Revenue

Joint R&D effort between UND and our private sector in this proposed work can result in technology advancement and improvement in scale-deposit treatment with definite impacts on environment, economy, and technology. Such collaboration in this applied research will benefit the PSP in terms of producing useful results with spending little time and money since the main part of the research will

be conducted at the UND by the faculty, post-doc, and PhD/MS students. This, in turn, can bring the PSP high return-on-investment values with high net profit and low cost or risk on investment.

In addition, upon the completion of this work, we graduate students with industry mindset who can work for the PSP and be the leader and workers in the ND energy sector in the future. Increasing our students' knowledge in scale deposition and production problems in the Williston Basin is a key element to this project since most of our students after graduation may be hired by operating or service companies in North Dakota.

IV. New Job Creation and Job Retention

Considering job creation, we can look at the *job creation index,* which is a measure of net hiring of full- and part-time adult workers. In the US, the index score is derived by subtracting the percentage of American workers who say their employers are 'firing' from the percentage of workers who say their employers are 'hiring'. North Dakota, a state relying heavily on the energy sector which was at the top of the rankings in six of the previous eight years and never outside the top 10, has now dropped into the bottom 10 (compare the job-creation index score of +21 in North Dakota to that of +40 in Nevada) [*Gallup*[1], 2017]. Therefore, the top priority in North Dakota has to be job creation; the necessary key to drive shared and sustainable economic growth. To achieve this goal, we seek for new scale inhibition technology from this work that can be a first step towards production, manufacturing, and small business establishment leading to hiring work-force, engineers, and graduates from the state of North Dakota.

UND-PE is currently the only Petroleum Engineering program offered in ND. Injection of research funded by State/Government sectors, especially during the current downturn in the oil and gas industry, is essential in order to support the department to perform applied research projects in conjunction with the industry, thus attracting more students to the program and producing more hands-on graduates to be working in the energy sector in North Dakota.

[1] http://www.gallup.com/topic/job_creation.aspx

V. Plans to Open Manufacturing Facility in North Dakota:

The commercialization of new scale inhibitors, chemicals, and treatment materials in the Williston Basin is now even more realistic and desirable than any time. The downturn in petroleum industry during the past two years (owing to the low oil prices) has caused an industry-wide focus on the maintenance of currently producing wells (e.g. avoid scale deposition) rather than drilling and completion. Therefore, successful completion of this project can lead to designing and producing effective inhibitors that can be marketed and sold to the Williston Basin oil industry.

A four-step will be sought for marketing the new products/chemicals from this research:

A. Understand the competitive market
B. Identify target market and customer companies
C. Create mix of marketing strategies
D. Create ***BUZZ*!**

VI. Environmental Impact:

Successful completion of this research can result in lower production decline rates in the Williston Basin, which means less need for workover jobs and *less fresh water usage* along with less amount of *liquid waste* produced from scales and treatment jobs; key outcomes with substantial positive environmental impacts on oil industry activities in the state of North Dakota.

VII. Impact on UND (Research University):

Conducting this proposed work will involve a number of undergraduate and graduate students at the University of North Dakota (UND) towards their final projects, theses, and dissertations. This will be beneficial in terms of graduating students with industry mindset and hands-on experience who are familiar with production challenges in North Dakota. In addition, producing high-quality publications from the work of M.S. and Ph.D. students will promote research and technology development in the PE department, at UND, and in the state of North Dakota. Furthermore, the success of these graduates and their industry-related projects will motivate more students from North Dakota to study Petroleum Engineering at UND.

Additionally, conducting this applied research is well in line with the **Mission of the Oil and Gas Research Council** [2] **(North Dakota Industrial Commission)** which is "*to promote the growth of the oil and gas industry through research and education*."

Why the Project is Needed

The economic/environmental impact of scale deposition on oil industry worldwide is troublesome. It is estimated that the adverse economic impact of scale problem on oil production in North and South America is as high as $600 million each year, not to mention its negative environmental impact. Therefore, a novel solution to this major production problem in the Williston Basin, North Dakota is necessary.

STANDARDS OF SUCCESS

Success will be measured based on the timely completion of the proposed tasks, the achievement of project milestones, quarterly reports as well as peer-reviewed publications and patents produced in this research.

The long-term value of this project to North Dakota oil industry can be ultimately realized by the full commercialization and utilization of the materials and technologies invented. This comprehensive research on the scaling process in the Williston Basin can stand out from several aspects when compared to a small number of available studies conducted in this area in the Williston Basin, ND. Some of the major distinguishing features of this proposed research are as follows:

- Compiling a bank of data from the Williston Basin oilfields with specific reference to the scale inhibition/treatments methods practiced so far. Such database, which does not exist in an integrated form, may be used and referred to in the future research on production problems in the Williston Basin, ND.

[2] http://www.nd.gov/ndic/ogrp-infopage.htm

- The impact of different parameters on scale deposition in the Bakken and Three Forks Formations will be determined through experiments, modeling/simulation, and advanced data-mining techniques.
- Studying the parameters involved in hydraulic fracturing treatments, farcking fluids, and scale inhibition programs currently practiced in the Williston Basin will help us to pinpoint the problem to significant parameters and challenges industry is facing with today in the Williston Basin.
- The access of PE department at UND to various commercial software licenses, which are available for this research project, will provide a good understanding of the scaling and other production problems in the Williston Basin.
- The presence of ***BARR Engineering Co.***—an active company in North Dakota in environmental and engineering projects— with provision of their technical support through the presence of their employees in this study adds great value to the project.
- ***Creedence Energy Services, LLC*** is a tremendous asset in this project as they have done and are conducting extensive scale treatments throughout the Williston Basin.
- Finally yet importantly, one great aspect of this research is the field implementation and testing of the new chemicals that we formulate in our labs in Williston Basin, Bakken wells. ***Creedence Energy*** will facilitate such field tests by which we can test the effectiveness of several inhibition/treatment scenarios and come up with better understanding of the scaling process and optimal inhibition techniques in the Williston Basin. ***This adds a great value to this project, as not many companies would be willing to have such a collaboration with academia that they let academia test their chemicals and products in the field.***

BACKGROUND/QUALIFICIATIONS

Dr. Hadi Jabbari, an assistant professor at **UND-PE department** is the Principal Investigator (PI) of the project. After his several years of experience working in the field (as a Production Engineer on offshore platforms) and in the office (as a Reservoir Engineer), Dr. Jabbari joined academia to develop industry-related research projects. He will supervise the entire project and is responsible for

interaction with other team members on a daily basis and managing the overall progress of the work to the final stage, ensuring that all milestones are fulfilled on a timely manner and at highest quality. He will also arrange regular meetings to exchange the findings of the tasks performed by each team member and the industry partner (PSP) to guide a smooth progress of the project. Tracking the project budget and expenditure is also his responsibility.

Dr. Minou Rabiei, an assistant professor at **UND-PE department** is the academic Co-PI in this project. With her education background and work experience in data analytics, data-mining and numerical simulations, she will be the main lead in data management and scale-prediction model development.

Mr. Kevin Black (KB) and *Mr. David McAtee* (DM) from ***Creedence Energy Services***, one of the private sector collaborators in this project located in Minot, ND, will play a key role throughout the project. They have done extensive scale testing throughout the Williston Basin and have worked with many companies to develop novel scale inhibitor technologies. With their core expertise in scale inhibition and remediation, they will provide valuable input specifically in task T-2 (see **Table 1**) as well as providing information on the current scale practices in the Williston Basin.

Dr. Scott Korom from ***BARR Engineering*** will collaborate with us in performing the water analysis task BARR will provide water resources engineering and environmental consulting services to clients across the US and around the world.

MANAGEMENT

The PI is the main facilitator of communication among research members in this project. There will be weekly meetings to check the progress of different tasks, find any potential obstacles, and establish the way forward. Industry partner and subcontractor (if need be) will attend meetings via conference calls or in-person when necessary.

The private collaborators will have a number of visits to UND to discuss the progress of the project. UND project team members together with the postdoc fellow and the two graduate students will visit lab facilities and well-sites in ***BARR Engineering*** and ***Creedence Energy Services*** as required.

The graduate students will be involved in most of the tasks for learning purposes, while they will be working more deeply in specific tasks towards their research projects. Dr. Jabbari will be the main advisor for the first graduate student (G1), and Dr. Rabiei will serve as the main advisor for the second graduate student (G2). The industry collaborators will act as the co-advisors for these graduate students. Weekly meetings between G1 and G2 and their main advisors will be scheduled to closely monitor the progress of graduate students. In addition, four undergraduate students will be nominated to work on their senior design project as part of the tasks listed in the schedule in **Table 1**. As the scope of undergraduate projects is small and lasts for almost four months, each student will be assigned to work on one or part of the tasks during the year that the project is conducted. These students will be asked to attend the weekly meetings with graduate students during the term of their project. The entire research team, including industry partners and students, will communicate through email and phone calls as necessary.

TIMETABLE

The schedule in **Table 1** gives an overview of the project's timeframe.

Table 1: Proposed tasks and project timeline

Tasks and Sub-Tasks	Start	End	Budget Year 1						Budget Year 2						Budget Year 3					
			MONTHS																	
			10 11	12 1	2 3	4 5	6 7	8 9	10 11	12 1	2 3	4 5	6 7	8 9	10 11	12 1	2 3	4 5	6 7	8 9
T-1: Preliminary Studies and Data Gathering			1st Public kick off Presentation (receiving initial feedback)																	
T-1.1: Data, well reports & core sampling	1-Oct-17	31-Jan-18	■	■																
T-1.2: Prepare summary report of past work	1-Dec-17	31-Mar-18		■	■															
T-1.3: Comparison and assessment of current technologies	1-Dec-17	31-May-18		■	■	■														
Evaluation Point		31-May-18				o														
T-2: Data Acquisition: Lab Analysis & Simulations			2nd Public Presentation																	
T-2.1: Water Analysis	1-Feb-18	31-Jul-18			■	■	■													
T-2.2: Scale Characterization	1-Feb-18	30-Sep-18			■	■	■	■												
T-2.3: Rock Characterization	1-Feb-18	30-Sep-18			■	■	■	■												
T-2.4: Scaling Index (SI)	1-Aug-18	30-Nov-18						■	■											
T-2.5: Data Visualization & Mapping	1-Dec-18	31-Mar-19								■	■									
T-2.6: Molecular Dynamics Simulation (MDS)	1-Apr-19	30-Sep-19				■	■	■	■	■	■	■	■	■						
T-2.7: Experimental Study: Coreflood Testing	1-Aug-19	30-Sep-19				■	■	■	■	■	■	■	■	■						
Evaluation Point		30-Sep-19												o						
T-3: Data Interpretation & Management			3rd Public Presentation																	
T-3.1: Data Analysis	1-Dec-18	31-Jul-19							■	■	■	■								
T-3.2: Data mining method selection	1-Aug-19	31-Sep-19												■						
T-3.3: Classification algorithm development	1-Aug-19	31-Jan-20												■	■	■				
T-3.4: Interpretation of the results	1-Dec-19	31-Mar-20														■	■			
T-3.5: Development of predictor models	1-Feb-20	30-Apr-20															■	■		
Evaluation Point		30-Apr-20																o		
T-4: Presentation of results			Final Presentation of the results																	
T-4.1: Final report, input and output data files	1-Jun-20	30-Sep-20																	■	■

BUDGET

As shown in the table below, the total cost of the project is $1,060,205.60. We request a total of $435,433.23 (direct costs: $316,067.07; indirect costs: $119,366.16) from NDIC-OGRC, which accounts for almost 41% of the total cost, to undertake the study described above. A large portion of the requested funds will go towards supporting a postdoctoral fellow and two graduate students. The private company (***Creedence Energy***) provides a total of $336,000.00 as matching fund in the form of in-kind contribution (their letter of commitment is attached to this application). UND provides a cost share of $288,772.37 in the form of contributed salary, fringe benefits, and student tuition for UND

participants. In addition, UND policies require a 39% overhead to cover facilities and other support provided by our institution. **Table 2** provides an itemized list of the project's costs.

Table 2: Itemized list of the project's cost.

Year	Project Associated Expense	NDIC's Share	Applicant's Share (Cash)	Applicant's Share (In-Kind)	Other Project Sponsor's Share *(Creedence Energy)*
1	$329,821.87	$167,564.41	$0.00	$96,257.46	$66,000.00
2	$419,191.87	$133,934.41	$0.00	$96,257.46	$189,000.00
3	$311,191.87	$133,934.41	$0.00	$96,257.46	$81,000.00
Total	$1,060,205.60	$435,433.23	$0.00	$288,772.37	$336,000.00

A. PERSONNEL

PI and Co-PI request 1 month of summer salary and associated benefit for each year. This will help them to work on the project during the summer in addition to the time that they need to allocate to the project during the academic year. The requested amount of salary per year is $9,001.7 plus $3,000 of fringe benefits for Dr. Jabbari and $8,688.9 plus $1,351.3 of benefits for Dr. Rabiei. UND will provide the same amount of match of one month salary and benefits for both Dr. Jabbari and Dr. Rabiei.

It is necessary to employ a postdoctoral researcher on a full-time basis who will have major contribution in working on the project for 3 years. The total requested fund to support this researcher is $50,189.40 per year (9 months of salary at $4,000 plus $1,576.6 benefit per month).

B. OTHER PERSONNEL

Two graduate students will contribute an effort of 12 months per year. These individuals will be trained by the PI and Co-PI to conduct scientific research and accomplish the ultimate goals of the project. One will mostly focus on experimental studies and lab work while the other student will be involved mainly in data analytics and data interpretation.

We are requesting $10,812.24 per year for each student from NDIC, which will go towards 9 months of salary and benefits. UND will provide a total of $7,208.16 per year, for the remaining 3 months of

salary for the two graduate students. In addition, $40,000 per year as UND in-kind share will go towards tuition fees for the two students.

C.EQUIPMENT

An "*atmospheric scaling test setup*" is required for the lab analyses performed in year 1 and 2 of the project. The estimated cost of this equipment and other auxiliary apparatus is around $10,000.

D. TRAVEL

Travel is estimated on the basis of UND travel policies which can be found at https://und.edu/finance-operations/accounting-services/travel-employee.cfm. Travel may include well-site visits, professional meetings, and conference participation as explained by the scope of work and in the budget. Two field trips per year to visit the Williston Basin and the private partner's facilities are anticipated. Each visit is planned for two persons for two days and where possible UND's vehicle will be used for each trip to minimize the costs. The estimated travel costs of $2,500/year will also enable the researchers to travel to professional conferences to present findings associated with the investigation.

E. SUBCONTRACTOR

One of the major tasks in this project involves analysis of the water samples from Bakken wells. **BARR Engineering Co.** will collaborate with us in handling the water sampling and the interpretation of data acquired from lab tests at UND all of which performed at a discounted rate of $17,000.

Finally, the following tables provide the details of the anticipated expenses to complete this proposed research:

Table 3: Summary of the yearly expenses associated with the project

Year	NDIC Share		UND Share		Industry Share		Total	
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
1	$123,355.69	$44,208.72	$69,249.97	$27,007.49	$66,000.00		$258,605.66	$71,216.21
2	$96,355.69	$37,578.72	$69,249.97	$27,007.49	$189,000.00		$354,605.66	$64,586.21
3	$96,355.69	$37,578.72	$69,249.97	$27,007.49	$81,000.00		$246,605.66	$64,586.21
Total	$316,067.07	$119,366.16	$207,749.91	$81,022.46	$336,000.00		$859,816.98	$200,388.62
Total	**$435,433.23**		**$288,772.37**		**$336,000.00**		**$1,060,205.60**	

Table 4: Details of the project expenses in year 1

	Year 1, NDIC Share			Year 1, UND Share			Industry Sponsor's Share
EXPENSES, Personnel	**Salary**	**Benefit**	**Tuition**	**Salary**	**Benefit**	**Tuition**	
Hadi Jabbari, PI	$9,001.67	$3,000.00		$9,001.67	$3,000.00		
Minou Rabiei, Co-PI	$8,688.89	$1,351.25		$8,688.89	$1,351.25		
Postdoctoral Fellow	$36,000.00	$14,189.40					
Two Graduate Students	$21,600.00	$24.48		$7,208.16		$40,000.00	
Total Personnel		**$93,855.69**			**$69,249.97**		
EXPENSES, Nonpersonnel							
Supply/Materials-Professional	$17,000.00						$65,000.00
Equipment>$5,000	$10,000.00						
Travel, Meetings, Conferences	$2,500.00						$1,000.00
Total Nonpersonnel		**$29,500.00**					**$66,000.00**
Total Direct Expenses	$123,355.69			$69,249.97			$66,000.00
F&A (39% of Direct Costs)	$44,208.72			$27,007.49			
TOTAL EXPENSES		**$167,564.41**			**$96,257.46**		**$66,000.00**

Table 5: Details of the project expenses in year 2

	Year 2, NDIC Share			Year 2, UND Share			Industry Sponsor's Share
EXPENSES, Personnel	**Salary**	**Benefit**	**Tuition**	**Salary**	**Benefit**	**Tuition**	
Hadi Jabbari, PI	$9,001.67	$3,000.00		$9,001.67	$3,000.00		
Minou Rabiei, Co-PI	$8,688.89	$1,351.25		$8,688.89	$1,351.25		
Postdoctoral Fellow	$36,000.00	$14,189.40					
Two Graduate Students	$21,600.00	$24.48		$7,208.16		$40,000.00	
Total Personnel		**$93,855.69**			**$69,249.97**		
EXPENSES, Nonpersonnel							
Supply/Materials-Professional							$188,000.00
Equipment>$5,000							
Travel, Meetings, Conferences	$2,500.00						$1,000.00
Total Nonpersonnel		**$2,500.00**					**$189,000.00**
Total Direct Expenses	$96,355.69			$69,249.97			$189,000.00
F&A (39% of Direct Costs)	$37,578.72			$27,007.49			
TOTAL EXPENSES		**$133,934.41**			**$96,257.46**		**$189,000.00**

Table 6: Details of the project expenses in year 3

	Year 3, NDIC Share			Year 3, UND Share			Industry Sponsor's Share
EXPENSES, Personnel	**Salary**	**Benefit**	**Tuition**	**Salary**	**Benefit**	**Tuition**	
Hadi Jabbari, PI	$9,001.67	$3,000.00		$9,001.67	$3,000.00		
Minou Rabiei, Co-PI	$8,688.89	$1,351.25		$8,688.89	$1,351.25		
Postdoctoral Fellow	$36,000.00	$14,189.40					
Two Graduate Students	$21,600.00	$24.48		$7,208.16		$40,000.00	
Total Personnel		**$93,855.69**			**$69,249.97**		
EXPENSES, Nonpersonnel							
Supply/Materials-Professional							$80,000.00
Equipment>$5,000							
Travel, Meetings, Conferences	$2,500.00						$1,000.00
Total Nonpersonnel		**$2,500.00**					**$81,000.00**
Total Direct Expenses	$96,355.69			$69,249.97			$81,000.00
F&A (39% of Direct Costs)	$37,578.72			$27,007.49			
TOTAL EXPENSES		**$133,934.41**			**$96,257.46**		**$81,000.00**

CONFIDENTIAL INFORMATION

There is no confidential information.

PATENTS/RIGHTS TO TECHNICAL DATA

It is very likely that in this research project we design new chemicals and more-effective inhibition techniques, which can be patented in the future.

STATUS OF ONGOING PROJECTS (IF ANY)

N/A

Appendix A: References

- Cenegy, L.M., C.A. McAfee, and L.J. Kalfayan. 2011. Field study of the physical and chemical factors affecting downhole scale deposition in the North Dakota Bakken Formation. SPE 140977-MS, paper presented at the SPE International Symposium on Oilfield Chemistry, 11-13 April, The Woodlands, TX.
- Cook S., H. Lu, and J. Cutler, C. Haugen, L. Cenegy, and C. McAfee. 2015. Scale squeeze fractured reservoirs in the Bakken, North Dakota. SPE 174966-MS, paper SPE presented at the Annual Technical Meeting and Exhibition held in Houston, TX, 28-30 September.
- Crabtree, M. et al. 1999. Fighting scale-removal and prevention. Schlumberger oilfield review, Autumn: 30-45.
- Frenier, W.W. and M. Ziauddin. 2008. Formation, removal, and inhibition of inorganic scale in the oilfield environment. *SPE Book, Society of Petroleum Engineers*.
- **Jabbari, H.**, A. Riopelle, A. Osborn, J. Park, and W. Eerdmans. 2016. Scale formation and inhibition in the Williston Basin, PTRE 484; Senior Design I, UND, PE Department.
- Langelier, W.F. 1936. The analytical control of anti-corrosion water treatment. J. Am. Water Works Assoc. 28: 1500-1521.
- Liu, K., M Ostadhassan, **H. Jabbari**, and B. Bubach. 2016a. Potential Application of Atomic Force Microscopy in Characterization of Nano-pore Structures of Bakken Formation. SPE-180276, SPE Low Perm Symposium, 5-6 May, Denver, Colorado, USA.
- Liu, K., M Ostadhassan, B. Bubach, and **H. Jabbari**. 2016b. Bakken Formation Shales Nano-Scale Analysis Understand Mechanical Parameters. ARMA-2016-153, 50th U.S. ARMA Rock Mechanics/Geomechanics Symposium, 26-29 June, Houston, TX.
- Nancolas G.H., L. Wang, Z.J. Henneman, and P.P. Emmerling. 2007. New models for scale formation and dissolution. Paper 07050 presented at the NACE International Corrosion/07, Houston.
- Ostadhassan, M., Z. Zeng, **H. Jabbari**. 2012. Anisotropy Analysis in Shale by Acquiring Advanced Sonic Data-Bakken Shale Case Study, AAPG 2012 Annual Convention & Exhibition, Long Beach, CA, USA.
- Sorbie, K.S. 2012. A simple model of precipitation squeeze treatment. SPE 155111-MS, presented at the SPE International Conference on Oilfield Scale, 30-31 May, Aberdeen, UK.
- Stalker, G., G.M. Graham, D. Oliphant, M. Smillie. 2004. Potential application of viscosified treatments for improved bullhead scale inhibitor placement in long horizontal wells— a theoretical and laboratory approach. Paper SPE 87439 presented at the SPE International Oilfield Scale, Aberdeen, 26-27 May.
- Stalker, R., J.R. Wright, R. Fitzpatrick, and G. Graham. 2012. Modeling squeeze treatment of fractured reservoir zones. SPE 156024-MS, paper SPE presented at the International Conference on Oilfield Scale, 30-31 May, Aberdeen, UK.
- Stiff, H.A. and L.E. Davis. 1952. A method for predicting the tendency of oil field waters to deposit calcium carbonate. Trans. AIME 195: 213-216. SPE 952213-G.
- USGS. 2013. Assessment of undiscovered oil resources in the Bakken and Three Forks Formations, Williston Basin Province, Montana, North Dakota, and South Dakota. National Assessment of Oil and Gas Fact Sheet.

Appendix B: List of Preliminarily Selected Chemicals

Tables 7 and **8** list the chemicals to be investigated and evaluated which are currently used in the industry and in the Bakken Formation.

Table 7. List of chemical used for scale treatment

Scale Type	Chemical	Structure	Function
Calcium carbonate, sulphate ,barium and strontium	Phosphonate	$C{-}PO(OH)_2$ $C{-}PO(OR)_2$	Inhibitor
	polymeric	$OC\text{-}C_6H_4\text{-}COO\text{-}CH_2\text{-}CH_2\text{-}O$	Inhibitor
	Phosphino-polycarboxylate acid polymer	C3H4O2·H3O2P·Na)x	Inhibitor
	Polyvinyl sulfonic acid	$CH_2CHSO_3H + H_2O$	Inhibitor
	Sulfonated polyacylate copolymer	([-CH_2-CH(CO2Na)-]n	Inhibitor
carbonate	Hydrochloric, formic acid	HCO_2H	removal
	Acetic acids	CH_3CO_2H	removal
Sulphate	diethylenetriaminepentaacetic acid	$C_{14}H_{23}N_3O_{10}$	
Silica and sodium chloride	Acrylamide polymer	((-$CH_2CHCONH_2$-)	Inhibitor
	polyamines	$H_2N–(CH_2)_3–NH_2$	Inhibitor
	borate	B(OH)3 +2H2O ⇌ B(OH)−4 + H_3O+).	Inhibitor
Iron based	imidazolines	C3H6N2	Inhibitor
	Ammonium compound	$[CH_3(CH_2)nN(CH_3)_2CH_2C_6H_5]$+Cl−	Inhibitor
Iron oxides	Sulfuric acid	H_2SO_4	removal
	Phosphoric acid	H_3O_4P	removal
	Nitric acid	HNO_3	removal
	Sulfamic acid	H_3NSO_3	removal
copper	Alkaline oxidizer, hydrochloric complexers	$C_2H_8N_2$	removal
Silica and silicates	Fluorosilicic acid	$(H_3O)_2SiF_6$	removal
Halite	Fresh water	H_2O	removal

Table 8. List of scale inhibitor used in the Bakken Formation

Trade Name	Supplier	Function	Ingredient
MX 2-2822	Multichem	Scale Inhibitor	Methyl alcohol, phosphate of a diamine sodium salt
FDP-M1066-12	Haliburton	Scale Inhibitor	Methanol, Phosphonate of a diamine, sodium salt
MC S-2510T	Multichem	Scale Inhibitor	Ethylene Glycol
WSI 3607	JACAM	Scale Inhibitor	Ethylene Glycol,Methanol
Scaletrol 767W	Baker Hughes	Scale Inhibitor	Methanol, organic phosphonate
Scalesorb 3	BHI	Scale Inhibitor	Calcined Diatomaceous earth, amino tri(methylene phosphonic acid), phosphonic acid, Crystalline Silica Quartz
Gyptron T-106	Champion Technologies	Scale Inhibitor	Methanol, Hydrochloric acid
Gyptron T-475	Champion Technologies	Scale Inhibitor	Ethylene glycol, methanol, amine phosphonate5,potassium chloride, amine phosphonate5,potassium salt
SI -14W	SANJEL	Scale Inhibitor	Methanol, phosphoric acid

Appendix C: Resumes of Project Personnel

HADI JABBARI Assistant Professor of Petroleum Engineering

Education

Institute	Major	Degree	Year
Petroleum University of Technology, Iran	Production Engineering	B.S.	2004
Sharif University of Technology, Iran	Reservoir Engineering	M.S.	2006
University of North Dakota	Petroleum Engineering	Ph.D.	2013

Appointments:

Institute	Position	Duration
UND, US	Asst. Prof., Petroleum Eng Department	Aug 2013-Present
EERC,US	Reservoir Engineer	Jan 2011-Jan 2013
UND, USA	Graduate Research Assist.	Aug 2009-Jan 2011
Petropars LTD, IRAN	Reservoir Simulation Engineer	Jan 2008-Aug 2009
PUT Research Center, IRAN	Research Engineer	Jan 2008- Aug. 2009
Iranian Offshore Oil CO. IRAN	Production Engineer	Jan 2007- Aug 2008

Selected Publications

- Jabbari H., M. Rabiei, K. Afsari, A. Monk, and M. Ostadhassan. 2016. Thermally-Induced Wettability Alteration from Hot-Water Imbibition in Naturally Fractured Reservoirs, Fuel Journal, submitted for revision.
- Liu, K., M Ostadhassan, B. Bubach, H. Jabbari. 2016. Bakken Formation Shales Nano-Scale Analysis Understand Mechanical Parameters. ARMA-2016-153, 50th U.S. ARMA Rock Mechanics/Geomechanics Symposium, 26-29 June, Houston, TX.
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- M. Ostadhassan, H. Jabbari, S. Zamiran, A. Osouli, B. Oster and B. Bubach. 2015. Probabilistic Time-Dependent Thermo-Chemo- Poroelastic Borehole Stability Analysis in Shale Formations -Bakken Case Study. American Rock Mechanics Association.
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- Jabbari, H. and S. Benson. 2013. Design of Transverse Hydraulic Fractures from a Horizontal Well in the Bakken Formation: Recipe for Success, presented at the 47th ARMA held 23-26 June 2013 in San Francisco, CA.
- Jabbari H. and Z. Zeng. 2011. Hydraulic Fracturing Design for Horizontal Wells in the Bakken Formation. ARMA 11-128, presented at the 46th ARMA held 24-27 June 2012 in Chicago, IL.
- Jabbari H., Z. Zeng, and M. Ostadhassan. 2011. Impact of In-Situ Stress Change on Fracture Conductivity in Naturally Fractured Reservoirs. ARMA 11-239, presented at the 45th ARMA held 26-29 June 2011 in San Francisco, CA.

- Ostadhassan, M., Zeng, Z, H. Jabbari. 2011. Using Advanced Acoustic Data to Determine Stress State Around the Wellbore. ARMA, 11-319, presented at the 45th ARMA held 26-29 June 2011 in San Francisco, CA.

Research Support

- Venture Grant: An Integrated Software Package for Data Processing, Modelling and Simulation of Unconventional Reservoirs; 2017-18; Research ND; Co-PI; $100,000 (Granted)
- Continuation of Underground Coal Gasification Study in Western North Dakota; 2014-15; NDIC; Co-PI; $719,958 (Granted)
- Submicron-Scale Integrated Reservoir Study of the Bakken Reservoir to Improve Field Data -- RESEARCH DEVELOPMENT & COMPLIANCE; SEED MONEY PROPOSAL, Since 2015, UND-Seed, Co-PI, $55,168 (Granted)
- Postdoc Funding Program; 2016-18; UND VP Research & Economy Division; Co-PI; $60,000 (Granted) SPE Awards for Academic Professional Development; PI; $1100, $2500, and $2400; (Granted)

MINOU RABIEI Assistant Professor of Petroleum Engineering

Education

Institute	Major	Degree	Year
Amirkabir University, Iran	Mining Engineering	B.S.	1998
South Bank University, UK	Information Technology	M.S.	2002
Curtin University, Australia	Petroleum Engineering	Ph.D.	2012

Appointments:

Institute	Position	Duration
UND, US	Assistant Prof, Petroleum Engineering Dept.	Mar 15-Present
Curtin University, Australia	Associate Lecturer, Petroleum Engineering Dept.	Jun 14- Mar 15
	Research Assistant, Dept. of Maths & Statistics	Feb 09-Jun 10
Tehran University, Iran	Policy & Research Analyst, Dept. of Mining Eng.	Aug 05-Aug 06
Iranian Institute of Minerals Research and Application	Policy and Practice Analyst	Sep 04-Aug 05

Selected Publications

- Wang, H., Lei, G., Rabiei, M. (2017). A Novel Granular Profile Control Agent for Steam Flooding: Synthesis and Evaluation. SPE Western Regional Meeting.
- Jabbari H., M. Rabiei, K. Afsari, A. Monk, and M. Ostadhassan. 2016. Thermally-Induced Wettability Alteration from Hot-Water Imbibition in Naturally Fractured Reservoirs, Fuel Journal, submitted for revision.
- Jabbari, H., Ostadhassan, M., Rabiei, M. (2015). Study of Geomechanical Effects in CO2-EOR for Bakken Formation. SPE/CSUR Unconventional Resources Conference. Society of Petroleum Engineers (SPE). http://dx.doi.org/10.2118/175908-ms
- Gholami, R., Rabiei, M., Rasouli, V., Aadnoy, B., Fakhari, N. (2015). Application of quantitative risk assessment in wellbore stability analysis. Journal of Petroleum Science and Engineering, 135, 185-200. http://dx.doi.org/10.1016/j.petrol.2015.09.013
- Rabiei, M., Gupta, R., 2012. Intelligent knowledge management for identifying excess water production in oil wells. First International Conference on Petroleum and Mineral Resources. Kurdistan, Iraq.
- Rabiei, M., Gupta, R., 2011. Evolution from Water-Oil Ratio to Tree Based Classifier - A Novel Methodology for Effective Diagnosis of Water Production Mechanism in Oil Wells. Proceedings of the International Conference on SocProS, AISC 131, pp. 921 -930.
- Gupta, R., Rabiei, M., 2011. Wheedle out knowledge from data using ensemble classifiers - An effective diagnosis of water production mechanism in oil wells. Second International Conference on Computing (ICC). New Delhi, India.
- Rabiei, M., Gupta, R., Cheong, Y.P. and Sanchez, G., 2010. Transforming data into knowledge using data mining techniques: application in excess water production problem diagnosis in oil wells. SPE Asia Pacific Oil and Gas Conference & Exhibition (APOGCE), Brisbane, Australia, SPE 133929.
- Rabiei, M., Gupta, R., Cheong, Y.P. and Sanchez, G., 2010. A novel approach in extracting predictive information from water-oil ratio for enhanced water production mechanism diagnosis. APPEA Journal 50, pp. 567-579.
- Rabiei, M., Gupta, R., Cheong, Y.P. and Sanchez, G., 2009. Excess water production diagnosis in oil fields using ensemble classifiers. International Conference on Computational Intelligence and Software Engineering, IEEE 10.1109/CISE., pp. 1-4.

Research Support

- Venture Grant: An Integrated Software Package for Data Processing, Modelling and Simulation of Unconventional Reservoirs; 2017-18; Research ND; **PI; $100,000 (Granted)**

- EPSCoR Startup Fund for new Faculty; 2016-18; ND EPSCoR; **PI; $150,000 (Granted)**

- Postdoc Funding Program; 2016-18; UND VP Research & Economy Division; **PI; $60,000 (Granted)**

Appendix D: Relevant UND Laboratory Facilities and Capabilities

The research team has access to advanced laboratory facilities both internal (at UND) and external (at PSP sites) to perform the proposed research. The access to the laboratories at UND is not restricted but a nominal laboratory service fees to be expended that have been considered in the budget.

Water Analysis: Environmental Analytical Research Laboratory at UND (EARL)

- SOLAAR M6 Atomic Absorption Spectrometer (Cation Analysis)
- DIONEX DX-120 Ion Chromatograph (Anion Analysis)
- SHIMADZU TOC/TN Analyzer (Carbon/Nitrogen Analyses)
- LECO SC-432DR Sulfur Analyzer (Sulfur Analyses)

Petroleum Engineering Laboratory (PE)

- Vinci EOR core flood system for polymer and chemical injection (CHEMFLOOD)
- Vinci Visual Fluid-Eval PVT system
- High Pressure Pump Hastelloy
- CSC Interfacial Tensiometer
- TKA209 Gas Permeameter
- TPI219 Helium Porosimeter
- Hassler Coreholder
- Advanced Attrition Test System
- Tracer IV-SD System
- Wettability Test
- Viscometer
- Rehometer
- Interfacial Tension Cell

Materials Characterization Laboratory (IES)

- Oxford Geospec2 NMR
- SEM (FEI Quanta 650 FEG, and Hitachi SEM)
- Rigaku Smartlab XRD
- Rigaku Supermini 200 x-ray fluorescence (XRF)
- OFITE 740 Gamma Ray Logger
- High-pressure porosimeter
- Micropore and Chemisorption analyzer (Autosorb-iQ-C Chemisorption with built in TCD)
- Malvern Zetasizer Nano ZS with NIBS
- PerkinElmer Lambda 1050 UV/Vis/NIR spectrophotometer

Appendix E: Letters of Support/Commitment

Letters of commitment from our industry partner and subcontractor are attached to this application.

resourceful. naturally.
engineering and environmental consultants

BARR

May 25, 2017

North Dakota Industrial Commisson

Re: DEVELOPMENT OF TESTING METHODS AND DESIGN OF INORGANIC SCALE TREATMENTS IN WILLISTON BASIN, NORTH DAKOTA

I strongly support Dr. Hadi Jabbari and his team on their proposal to reduce scaling problems in the Williston Basin and to commercialize their innovative scale treatment technologies to the oil and gas industry. I spent 20 years as a faculty member at UND in Geology and Geological Engineering. I was part of the team that initiated the new Department of Petroleum Engineering and I was on the search committee that selected Dr. Jabbari for his current faculty position. Having worked and published with Dr. Jabbari, I can a personally attest that he is a brilliant scholar and a rising faculty star in an exciting new program in the UND College of Engineering and Mines.

As to my expertise, I have done research on water quality issues, such as scaling, for over 30 years. I directed or supervised the Environmental Analytical Research Laboratory at UND for over 15 years and developed an intimate knowledge of how North Dakota geology influences water quality. I can say with confidence that there is no one else in the State of North Dakota with my mix of local geochemical knowledge and water quality analytical skills. Therefore, I am excited to contribute to this proposal.

My billing rate for a research project of this type would normally be $240/hour; however, in support of this proposal I will only charge 70% of this rate. For a subcontract fee of up to $17,000, I will assist Dr. Jabbari and his team in interpreting water analyses, characterizing scale to formation rock type, and determining the scaling parameters associated with the extreme salinity of the Williston Basin. I will make at least two trips to Grand Forks to meet with Dr. Jabbari and his team and I will teach student how they can contribute to the analytical effort so that project costs may be reduced and educational outcomes gained.

Sincerely,

Scott F. Korom, PhD, PE

Creedence Energy Services
PO BOX 3480
Minot, ND 58702

May 25, 2017

North Dakota Department of Commerce
1600 E. Century Ave., Suite 2
Bismarck, ND 58503 | 701.328.5300

RE: Support Letter for the Grant Proposal from UND Petroleum Engineering Department

Grant Review Committee Members:

As a North Dakota company specializing in scale remediation and prevention, Creedence Energy Services is excited to support the UND Petroleum Engineer Department's grant proposal for *"Development Of Testing Methods And Design Of Inorganic Scale Treatments In Williston Basin, North Dakota."* Creedence recognizes the direct economic impact and importance to the oil and gas industry in North Dakota by the research proposed by Assistant Professors Dr. Hadi Jabbari and Dr. Minou Rabiei.

Due to high concentrations of total dissolved solids found in brine produced from Bakken/Three Forks formations, wells inherently possess a serious risk of production decline and failure due to scale formation. If a well experiences a failure due to scale, the economic consequences are extraordinary. While some types of scale, such as calcium carbonate and iron sulfide, can be remediated by acidizing operations, other scales cannot be removed and production equipment must be replaced entirely.

The proposed project will focus on developing improved methods of evaluating scale formation risk and more effective inhibition solutions. Implementing the proper scale inhibition program, both in terms of application technique and product chemistry, can potentially save operators hundreds of thousands of dollars over the life a Bakken/Three Forks well. In other words, the cost of scale inhibition is merely a fraction of the cost associated with lost production and remediation operations.

Creedence commends UND's Petroleum Engineering Department's goal of pursuing practical research that directly benefits North Dakota's oil and gas industry and is fully committed to providing our time and effort over the next three years in travel, participation in advising students and staff, and video/audio interaction towards this proposal in the following estimated amounts:

1 trip/year for 3 years:

- Travel and accommodation = $1000 x 3 = $3,000

Consultation fee per day: $1,600/day

- 3 trips of 2 days for 2 staff engineers = $4,800 x 2 x 2 = $19,200

Meeting presentation, video/audio, consultation to staff and students:

- 1569 hours (total) x $200/hour = $313,800

Total commitment to UND/PE Department = $313,800 + $19,200 + $3,000 = **$336,000**

CREEDENCE
ENERGY SERVICES

Please consider these figures to be accurate and reflects a donation to UND with no expectations in return other than qualified students that are ready to face engineering challenges in North Dakota's oil and gas industry.

Regards,

Kevin Black
President
Creedence Energy Services

Year 1

Research University -NDIC

Name	Title
Hadi Jabbari	Faculty
Minou Rabiei	Faculty
Postdoc	Postdoctoral Fellow
Grad Student 1	3 month stipend from PE as in-kind
Grad Student 2	3 month stipend from PE as in-kind

NDIC Share

Research University- In-kind

Name	Title
Hadi Jabbari	Faculty
Minou Rabiei	Faculty
Grad Students	3 month stipend from PE as in-kind
Grad Students	Tuition

UND In-kind

Sub-Contractor

Name	Company
Scott Korom	BARR ENGINEERING CO

Private Sector

Name	Company
Kevin Black	Creedence Energy Services, LLC
David McAtee	Creedence Energy Services, LLC

Name	Company

UND
Creedence Energy Services, LLC
Indirect Costs

Total RND
UND in-kind
Industry Share

Months	Monthly Salary	Monthly Fringe
1	$9,001.7	$3,000.0
1	$8,688.9	$1,351.3
9	$4,000.0	$1,576.6
9	$1,200.0	$1.4
9	$1,200.0	$1.4

Months	Monthly Salary	Monthly Fringe
1	$9,001.7	$3,000.0
1	$8,688.9	$1,351.3
6	$1,200.0	$1.36
12		

hours	Hourly Pay	
100	$170.0	

Travel
2 Trips/2 people/2 days

Equipment
Equipment

Request from NDIC

hours	Hourly Pay	
165	$200.0	
160	$200.0	

Travel
1 Trip/2 people/2 days

Creedence Cash Reserved

hours	Hourly Pay	

Travel

Total Cash Reserved

Budget SUMMARY

Y1	Y2	Y3
$123,355.7	$96,355.7	$96,355.7
$66,000.0	$189,000.0	$81,000.0
$44,208.7	$37,578.7	$37,578.7
$167,564.4	**$133,934.4**	**$133,934.4**
$69,249.97	$69,249.97	$69,249.97

Research University

Funds Requested	Name
$12,001.67	Hadi Jabbari
$10,040.14	Minou Rabiei
$50,189.40	Postdoc
$10,812.24	Grad Student 1
$10,812.24	Grad Student 2
$93,855.7	

In-kind	Name
$12,001.67	Hadi Jabbari
$10,040.14	Minou Rabiei
$7,208.16	Grad Students
$40,000.00	Grad Students
$69,249.97	UND In-kind

Sub-Contractor

Funds Requested	Name
$17,000.0	

$2,500.0

Funds Requested
$10,000.0

$123,355.7

Private Sector

Cash Reserved
$33,000.0
$32,000.0
$65,000.0

$1,000.0

$66,000.0

Cash Reserved
$0.0

$189,355.7

Name
Kevin Black
David McAtee

Name

SUM
$316,067.1
$336,000.0
$119,366.2
$435,433.2
$288,772.37
$336,000.0

$1,060,205.6

$652,067.1

$436,000.0

Year 2

Title	Months	Monthly Salary
Faculty	1	$9,001.7
Faculty	1	$8,688.9
Postdoctoral Fellow	9	$4,000.0
3month stipend from PE as in-kind	9	$1,200.0
3 month stipend from PE as in-kind	9	$1,200.0

Title	Months	Monthly Salary
Faculty	1	$9,001.7
Faculty	1	$8,688.9
3 month stipend from PE as in-kind	6	$1,200.0
Tuition	12	

Company	hours	Hourly Pay

Company	hours	Hourly Pay
Creedence Energy Services, LLC	470	$200.0
Creedence Energy Services, LLC	470	$200.0

Company	hours	Hourly Pay

Monthly Fringe	Funds Requested
$3,000.0	$12,001.67
$1,351.3	$10,040.14
$1,576.6	$50,189.40
$1.4	$10,812.24
$1.4	$10,812.24
	$93,855.7

Monthly Fringe	Funds Requested
$3,000.0	$12,001.67
$1,351.3	$10,040.14
$1.36	$7,208.16
	$40,000.00
	$69,249.97

	Cash Reserved

Travel	
2 Trips/2 people/2 days	$2,500.0

Equipment	Funds Requested

Request from NDIC	$96,355.7

	Cash Reserved
	$94,000.0
	$94,000.0
	$188,000.0

Travel	
1 Trip/2 people/2 days	$1,000.0

Creedence Cash Reserved	**$189,000.0**

	Cash Reserved

Total Cash Reserved	**$285,355.7**

Year 3

Research University

Name	Title	Months
Hadi Jabbari	Faculty	1
Minou Rabiei	Faculty	1
Postdoc	Postdoctoral Fellow	9
Grad Student 1	3 month stipend from PE as in-kind	9
Grad Student 2	3 month stipend from PE as in-kind	9

Name	Title	Months
Hadi Jabbari	Faculty	1
Minou Rabiei	Faculty	1
Grad Students	3 month stipend from PE as in-kind	6
Grad Students	Tuition	12

UND In-kind

Sub-Contractor

Name	Company	hours

Private Sector

Name	Company	hours
Kevin Black	Creedence Energy Services, LLC	200
David McAtee	Creedence Energy Services, LLC	200
Equipment X	In-kind	

Name	Company	hours

Monthly Salary	Monthly Fringe	Funds Requested
$9,001.7	$3,000.0	$12,001.67
$8,688.9	$1,351.3	$10,040.14
$4,000.0	$1,576.6	$50,189.40
$1,200.0	$1.4	$10,812.24
$1,200.0	$1.4	$10,812.24
		$93,855.7

Monthly Salary	Monthly Fringe	Funds Requested
$9,001.7	$3,000.0	$12,001.67
$8,688.9	$1,351.3	$10,040.14
$1,200.0	$1.36	$7,208.16
		$40,000.00
		$69,249.97

Hourly Pay		Cash Reserved

Travel	
2 Trips/2 people/2 days	$2,500.0

Equipment	Funds Requested
Equipment	

Request from NDIC	$96,355.7

Hourly Pay		Cash Reserved
$200.0		$40,000.0
$200.0		$40,000.0
		$80,000.0

Travel	
1 Trip/2 people/2 days	$1,000.0

Creedence Cash Reserved	**$81,000.0**

Hourly Pay		Cash Reserved

Total Cash Reserved	**$177,355.7**