UNIVERSITY OF UND NORTH DAKOTA

Electrostatic Lubrication Filtration of Wind Turbine Oil Reservoirs
Submitted to:
Ms. Karlene Fine
North Dakota Industrial Commission Renewable Energy Council
State Capitol
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Funding Requested: $286,234

Submitted by:

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Renewable Energy Program

North Dakota Industrial Commission

Application

Project Title: Electrostatic Lubrication Filtration of Wind Turbine Oil Reservoirs

Applicant: University of North Dakota

Principal Investigator: Nicholas Dyrstad-Cincotta

Date of Application: 2/1/2021

Amount of Request: $286,234

Total Amount of Proposed Project: $584,614

Duration of Project: 16 Months

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ABSTRACT

Objective:

Many wind turbine field-operating failures are related to poor lubricant quality, consequentially resulting in gearbox bearing failure. Regular or unexpected maintenance can create significant downtime, resulting in lost revenue from a lack of power generation. ELF Technology, LLC. (ELF) has a patent pending for a novel product to maintain lubricant cleanliness within ISO 9000 standards to extend the usable life, prolong the gearbox's lifespan, and avoid costly turbine shutdowns, all of which will increase the value of the North Dakota wind industry. Proof of concept was established thorough beta testing and the development of two prototypes designed for large lubricant reservoirs of approximately 10,000 gallons with funding from a prior North Dakota Department of Commerce grant. Two scaled-down prototypes were designed and fabricated for future testing in the wind industry. The objective of the proposed project will add to previous developments by:

1) Conducting robust field demonstrations of the scaled-down ELF prototypes at two North Dakota wind turbines.
2) Fabricating and testing two additional units to optimize performance relative to the wind industry.
3) Further compaction and miniaturization of the technology to meet industry partner NextEra's needs.

Expected Results:

Results of the field validation tests will demonstrate that the ELF technology can filter and maintain turbine lubricant within ISO 9000 compliant status under field operating conditions. Testing at the UND facility will result in the system's optimized design, increasing flexibility and decreasing cost. The compact and miniaturized prototype will establish a larger business footprint in North Dakota's renewable energy field to support the ELF technology's business growth.

Duration: 16 months (suggested: 5/01/2021 – 9/30/2022)

Total Project Cost: $584,614

Participants:

University of North Dakota (UND) Institute for Energy Studies (IES), ELF Technology, LLC., and NextEra Energy, Inc.

PROJECT DESCRIPTION

Objectives:

The first objective is to conduct field trials to demonstrate the system's ability to clean the lubricant, validate the particle sensing technology's ability to monitor the lubricant condition, and generate real-time and continuous analysis. The data stream will incorporate telematics for daily measurements that will be made available to maintenance staff and turbine owners, as well as ELF and UND. Independent sampling will take place on a bi-monthly basis and analyzed by a third-party ISO certified independent lab to ensure that the in-line particle sensing device provides accurate and reliable data.

The team will fabricate two research units for testing at UND to accomplish the second objective of optimizing performance over a wide range of operating conditions while minimizing cost. Results from this testing will also provide the required input to accomplish the third objective of designing and fabricating a compact scaled-down prototype. Project sponsor NextEra will provide input and direction for these activities to ensure they meet wind industry needs.

The ELF and UND teams will also implement a detailed documentation process to ensure the newly developed ELF system's integrity, including verifying the particle sensing technology to return the used oil to an ISO 9000 Compliant status. ELF will then begin the process of obtaining ISO 9000 Certification, which will create an additional level of confidence in meeting the high standards of the renewable energy and wind industry.

We estimate project completion after 16 months from the release date of the funding. The benefits realized directly by the North Dakota renewable energy community include:

1) Eliminating the requirement to remove and replace the turbine gearbox for lubrication to achieve the manufacturer's recommended ISO compliance.
2) Ensuring the turbine is continuously operating with ISO compliant or cleaner oil.
3) Providing early indications of contaminant level surges and detecting the imminent failure of critical components.
4) Decreasing unnecessary downtime and the associated costs of reduced power generation from the scheduled maintenance of an off-line turbine.
5) Saving maintenance personnel time by reducing required sampling and lab testing.
6) Reducing costs associated with the acquisition and disposal of waste oil.

Methodology:

Task 1.0 – Project Management and Planning: UND will be responsible for completing this task, which includes all work elements required to maintain, revise, manage, and report on activities, including coordination of the project with ELF/LEC and other project participants. The ELF management team will collaborate with UND to develop the protocols and process improvements to be used. Consulting expertise will be provided by Peter Woods (ELF CTO) from Ontario, Canada, Tony Roisen and Pat Moran with Quality Stainless Inc. in Minneapolis, Minnesota, and Chase Rickson (ELF VP of Operations) from White Bear Lake, Minnesota.

Task 2.0 – Onsite Field Testing at Wind Turbines:

UND and ELF will package and transport the two existing prototypes to two North Dakota wind turbines, where they will be connected to gearbox lubricant reservoirs for a 360-day test. Turbine maintenance personnel will take bi-monthly samples for further analysis at an independent lab to obtain ISO certified results for wear metals, additives, viscosity, varnish potential, total acid number, and ISO particle numbers and cleanliness codes that are standard for oil analysis. This analysis will reveal the reliability of the new particle sensing technology to replace the previous method of sampling the lubricant and obtaining lab results needed for managing the reservoir's cleanliness.

ELF filter elements from one unit will be removed every 45 days and at the completion of the onsite field testing. A plate from the inlet, middle, and exit of the unit will be examined using SEM and XRD analysis to examine the amount and the nature of the material collected on the plates. This analysis, In conjunction with real-time particle sensor data, will indicate the rate at which the plates will start to lose effectiveness due to particle build-up. In a conventional gas phase electrostatic precipitator (ESP), particles are continuously removed from the plates via rapping. When applying the ELF Technology as an on-line oil filter, particles will accumulate on the plates, and the filter element will be replaced periodically as the particles build up. As these plates become coated with particles and lose their effectiveness, the build-up from oil cleansing will continually move towards the filter's exit plates. When the filter is first brought online with dirty oil in the reservoir, there will be a rapid build-up of particles on the filter plates as the inlet plates remove the bulk of the particulates. Once the filter has completed the initial cleaning, the ELF filter's particle loading will be lower. A comparison of the 45-day interval filter conditions, including the post-test SEM/XRD work, will indicate how quickly the plates develop a build-up of particulates, indicate the lifetime of the individual filters, and will help develop a realistic maintenance cycle. SEM analysis will also provide any evidence of corrosive wear.

Oil samples will be retrieved at the beginning, middle, and end of the test campaign. The UND team will analyze the oil with specific interest in the type and size of the particles and the results of the testing done at the independent lab. Evidence from previous work indicates that electrostatic oil cleaners can remove micron-size particulate contaminants and polymerized oil oxidation products. This observation will be verified as part of the analysis planned for this project.

Task 3.0 – Optimization and Scale-Down of the Elf Units:

Two additional ELF research units at windfarm scale will be fabricated to investigate the impact particle size loading, electrode spacing, applied voltage, and temperature on filtration efficiency to facilitate system optimization. The data from the system optimization will also be used to develop a scaled-down prototype of the technology. NextEra has indicated the need to reduce the size even further for full implementation in wind and other renewable energy industries. This miniaturization will require condensing the existing controls and electronics, and redesigning the exterior vessel and internal filter assembly.

Task 4.0 – Market Analysis and Establishing ISO Compliance:

This task will include market analysis and ISO compliance pathways for the ELF technology. UND will help ELF develop the commercialization plan, including the economic benefit and value stream related to the North Dakota renewable energy industry. The economic impact within the state of North Dakota includes the creation of new jobs, significant cost savings in turbine maintenance, and increased local economic stimuli. ELF anticipates developing a North Dakota fabrication facility to meet market demand from wind turbine operators and other industry implementation. UND will assemble and provide supporting documentation to ELF for ISO certification.

Anticipated Results:

This testing initiative will demonstrate that the ELF technology effectively maintains the cleanliness of turbine gearbox oil as measured by the ISO 4406 particle number and varnish potential. This technology will significantly reduce the number of submicron particulate contaminants and polymerized oil oxidation products, something conventional filters cannot achieve.

Results are also expected to refine the unit's design, such as the physical size, plate area, and other dimensions to ensure they are well-matched with the size of the turbine reservoir and the expected particle loadings.

Once the tests outlined in the scope of work are completed, we anticipate that the technology will be commercially deployable, with the subsequent adoption of the ELF technology by wind turbine owners in North Dakota. The savings expected by adopting the ELF technology will be attractive and encourage turbine owners to include this novel technology into their life-cycle maintenance budgets. Investment in this technology will reduce or eliminate manual sampling and testing of the lubricating oil, increasing power generation during times usually dedicated to turbine maintenance. Adopting the ELF technology will significantly increase lubricant life, improve turbine performance, and increase North Dakota's renewable energy competitiveness in the energy production market.

After introducing the technology to the local North Dakota wind industry, ELF management will address the national renewable energy community. Making the technology available to a broader audience will increase the need for the product and the creation of jobs in North Dakota. ELF Technologies will establish a larger business footprint in North Dakota to support growth as the interest in their technology increases. The initial ELF plant will occupy approximately 10,000 square feet and employ ten North Dakota workers. The facility will be built near UND, allowing for student participation in flex-time work programs that complement their academic pursuits. This partnership ensures a continuous stream of qualified future employees that already have experience and training with ELF technology. ELF will, in turn, invest in several local industries, from manufacturers and fabricators to end-users, including those partnered with ELF during the Department of Commerce project: Steffes Corp., Lunseth Plumbing & Heating Co., TriSteel Manufacturing Co., Red River Plumbing Supplies, Pro-Tec Powder Coating, and a host of other small businesses in the greater Grand Forks community. ELF will continue to pursue these business relationships as they work to bolster the local North Dakota economy.

Facilities and Resources:

UND has a fully equipped fabrication facility that includes a complete list of opportunities, including welding, machining, electrical, and installation services. Most of the fabrication research units and the scaled-down ELF prototype unit will be completed in UND shops, while local contractors will be hired for any pieces that require ASTM certification. UND's *Materials Characterization Lab* is supported by experienced technicians and analytical chemists with a vast array of equipment and capabilities, including SEM-EDX, ICP-MS, XRF, XRD, and thermal gravimetric analysis. Equipment from this lab will be used to examine the oil particle's nature and evaluate the particle deposition and buildup on the plates. The *Environmental Analytical Research Laboratory* houses principal analytical instruments, including an ion chromatograph, atomic absorption spectrometer, total organic carbon analyzer, sulfur analyzer, and ancillary equipment used to analyze the oil's quality before and after the testing campaign. More details on UND's equipment and facilities are in Appendix 2.

Techniques to Be Used, Their Availability, and Capability:

The Electrostatic Lubricant Filtration technology was an outgrowth of a decades-old development in the Electrostatic Air Filtration industry. KLEENTEK Industrial Co, Ltd.[1] first reported the application of an electrostatic filter to remove contaminants in oil-based systems. Their work demonstrates that in the case of an oil-based system, the creation of electrostatic fields within the filter stacks charge metallic contaminants, which are then drawn into a series of aluminum plates where they are permanently "welded," eliminating them from the source lubricant. Instead of the "once-through" operation of gas cleanup systems, oil filtration occurs on a 24-hour a day basis when used in a circulating system. This 24-hour filtration is essential, as the efficiency of the one-pass method in an oil-based system is low by conventional gas cleanup standards due to the dialectic properties and high viscosity of the oil. Since the oil is continuously recirculated, the cumulative effects of the relatively low removal efficiencies result in high overall collection efficiencies over time. The ELF apparatus removes contaminants down to the molecular level, which is not the case with their air filtration counterparts. Once the source liquid achieves a contaminant-free consistency, the fluid will remove varnish build-up within the turbine and further protect the internal mechanisms.

The system's design is based upon the fundamental equations governing electrostatic systems (see Appendix for details)[2]. The process, as designed for large oil reservoirs such as the gen-set in a coal power plant, involves a stainless-steel canister housing 18 aluminum plates separated by a medium. These plates provide a large collection area, which improves the overall efficiency and provides adequate surface area for particle collection, yielding a longer lifetime for the filter. When a large electric potential gradient is applied across the plates, an electrostatic field is generated, which attracts positively charged

[1] Sasaki, A. and Uchigama, S., A New Technology for Oil Management: Electrostatic Oil Cleaner, in *National Fluid Power Association and Society for Automotive Engineer, Inc.,* pp. 9-18, 2002.
[2] Kahn, S. and Dyrstad-Cincotta, N., Governing Equations for the ELF Technology Electrostatic Filtration, Concept Paper, 2020.

contaminant particles and binds them to the aluminum plates, thereby efficiently removing them from the source lubricant. The source lubricants will have a longer lifespan due to the reduced metal and polymerized oil oxidation contaminants. The ELF Technology can also remove existing varnish buildup from the interior surfaces when added to a "dirty" turbine, reducing or eliminating most maintenance activities. In a "clean" turbine, the ELF Technology is expected to eliminate or significantly reduce the varnish build-up on the turbine surfaces. Utilizing the ELF technology improves the bottom-line for turbine owners by decreasing the cost of frequent oil replacement and increasing revenue from continuous power production.

Preliminary Laboratory Scale Data:

ELF Technologies completed two large-scale beta field tests as part of the North Dakota Department of Commerce project: one at the Leland Olds Station and one at the Coyote Station, which are both electric generating plants located in North Dakota. The Coyote station plant has an oil reservoir size of 12,000 gallons and had starting particle counts of 9,030, 2,180, and 390 for the 4-, 6-, and 14-micron sizes, respectively. The Leland Olds plant has a 4,500-gallon oil reservoir and had starting particle counts of 1,250, 520, and 80 for the 4-, 6-, and 14-micron sizes, respectively. High removal efficiencies were obtained from both plants and had similar trends when plotted versus time, agreeing with our hypotheses (Figure 1). In both field tests, a reduction in particle counts to levels equivalent to fresh oil were obtained by the end of the testing cycle.

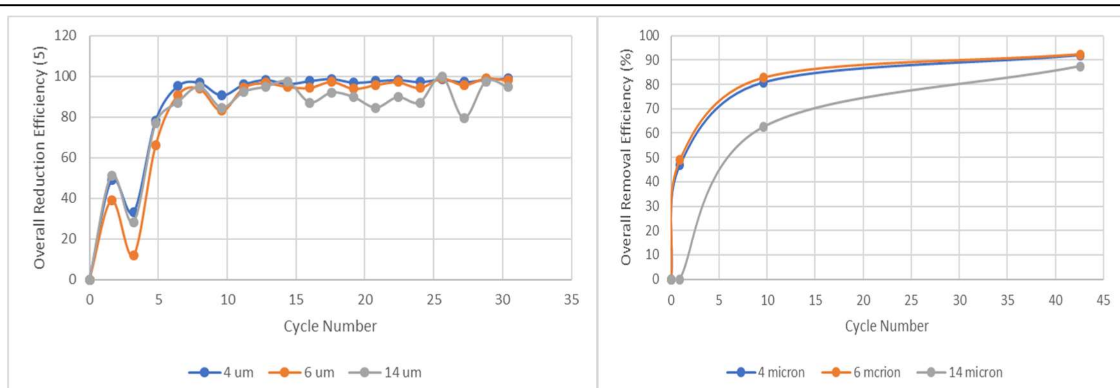

Figure 1. Reduction of particle count for field tests at the Leland Olds and Coyote Station, respectively

Environmental and Economic Impacts while Project is Underway:

The environmental impacts resulting from performing the proposed work are negligible. Waste streams produced as a result of this testing will be disposed of in conjunction with the UND Safety Office using existing waste disposal procedures currently in place. Economic impacts include employment opportunities for UND research faculty, students, and support staff. This project has the opportunity to strengthen the Grand Forks, ND economy by directly involving local businesses in ELF's supply chain, in addition to the economic impacts within UND.

Ultimate Technological and Economic Impacts:

The technical and economic impacts of the proposed technology include, but are not limited to, increased turbine efficiencies, reduced maintenance costs, fewer unscheduled shutdowns, and improved understanding of lubricant oil conditions. These impacts create education opportunities for significant strategic decisions, such as identifying and mitigating component fatigue before gearbox failure occurs.

There are currently 57,000 wind turbines with a combined capacity of 97,960 MW in the US, and 341,000 globally. Capturing a 3% market share over three years would represent 10,230 ELF wind turbine apparatus installations, or 284 installations per month. The market for wind turbines is growing: NextEra owns 14,000 turbines and expects a 50% increase of up to 21,000 turbines by 2025. This market increase presents an opportunity for yearly demand and continuous need for the product. The job growth and supply chain required to meet this demand translates to multitudes of jobs and millions of dollars of economic impact with a significant ripple effect throughout the North Dakota economy. The economic impact also grows exponentially when considering the variety of unique applications outside of wind farm arrays where an ELF unit can be utilized within the renewable energy sector.

Why the Project is Needed:

Turbine gearboxes use oil to reduce friction. As the turbine spins, tiny contaminant particles are generated from the metal-on-metal friction, which sticks to the turbine's internal components and creates what is known as "Varnish Build-up." The resultant varnish necessitates scheduled maintenance and can cause catastrophic failure, resulting in millions of dollars in damages. ***Mesh strainers and solid particulate filters have been trialed and were found to be inadequate for removing varnish and maintaining and cleaning the oil.*** The ELF system removes contaminants down to the sub-micron level.

Manufacturers such as General Electric and Siemens provide an ISO 4406:99 specification for lubrication oil to preserve the warranties for their systems and maintain operational integrity. This ISO code, which refers to the level of contaminants at various micron sizes, is typically in the 17/16/13 range for new oil. The left number represents the smallest particle size at 4 microns, the middle number represents a particle size of 6 microns, and the right number represents a particle size of 14 microns. The numbers themselves represent the particle count as an exponent of 2, such as 2^x where x is the number given in the ISO code; therefore, a change up to or down by one for the given numeric value represents doubling or halving the particle count, or the number of particles in that size range.

Operational staff receive scores of pass or fail for the lubricating fluid condition when sampled and tested. This score means the lab will report that 1) the oil is at or below the manufacturer's recommended level of contaminants, or 2) it exceeds the manufacturer's recommended level of contaminants. If the results yield a level of contaminants that exceeds the recommended requirements, the maintenance personnel remove the oil from the lubricant reservoir and replace it with new lubricant oil, representing a periodic cost of $1,500-2,200 in just supplies. The related labor costs are substantial, and the old, contaminated oil must be disposed of as hazardous waste, representing an additional cost.

Other industries will benefit from this technology; however, it will need to be demonstrated to deploy successfully at full scale. The primary target market, the renewable energy sector, is unlikely to implement an inadequately demonstrated technology. Independently ISO verified results of technology demonstration will lend further credence to the industry. One goal will be to establish ISO Certification to facilitate the implementation of the ELF technology in additional North Dakota energy sectors.

STANDARDS OF SUCCESS

The standards of success for the outcome of the proposed work are as follows:

- A successful trial at two ND wind turbines will demonstrate the efficacy of the electrostatic lubricant filtration technology by improving the quality of the turbine oil to an ISO level at or below 16/14/11, the NAS 1638 standard for clean oil.
- Developing a marketing plan, including the functional economic and financial models, to evaluate technology feasibility and commercial prospects.
- Obtaining ISO Certification.
- Incorporating the technology into existing maintenance regimens permanently, followed by commercial adoption at additional wind farms owned by NextEra.

- Creating optimal operating conditions defined through in-house parametric testing and miniaturization of the technology to a scale of at least ½.

BACKGROUND/QUALIFICATIONS

The proposed technical team has a long history of conducting large, interdisciplinary, and multi-organizational research projects.

Credentials, capabilities, experience, and commitment of key personnel:

Mr. Nicholas Dyrstad-Cincotta, B.S. and M.S. in Mechanical Engineering and current UND IES Engineer, will serve as the PI for the project. His research is primarily in the design, fabrication, programming, and testing of energy production systems. He has worked with IES for six years on various research projects, focusing on supercritical water desalination, rare earth element extraction, carbon capture, and chemical looping combustion. Mr. Dyrstad-Cincotta has served as the technical lead on the ELF project's prior development at UND and is the PI on a companion project support by the Lignite Energy Council.

Mr. Junior Nasah, Manager of Major Projects at UND IES, will serve as UND's program manager for the project. He has over ten years of experience in the experimental bench units of advanced combustion systems, fluid-bed based technology development, and high-temperature applications. As the project manager, he will provide mentorship to Mr. Dyrstad-Cincotta and allocate the resources required to complete the project successfully.

Mr. James Rickson, President & CEO of ELF, will be responsible for budgets, scheduling, purchasing, customer relations, sales, and the overall mission. Mr. Rickson will utilize his experience, current resources, and the comprehensive team he has assembled over the past decade to fulfill these responsibilities.

MANAGEMENT

The UND IES and ELF company have assembled a team to perform the proposed work. This team has the expertise required to develop the process by which the ELF unit's validity and marketability will be assessed and implemented by the wind industry. Mr. Nicholas Dyrstad-Cincotta, project PI, will be responsible for managing resources and schedules. He will also be responsible for coordinating all tasks within the UND IES and will ensure all personnel, equipment, and other resources will be made available to conduct the project efficiently. Mr. Junior Nasah will serve as the program manager, accepting responsibility for meeting coordination with project participants or sponsors. A resource manager will be dedicated to managing the project's financial account, spending rates, and procurement.

The project has been organized by task, with leads or team members accepting responsibility for completing each task. The UND IES will be responsible for overall project management. ELF will be responsible for overseeing communications and scheduling turbine field demonstrations with NextEra in Task 2, with assistance from UND for transportation and hookups. UND, with assistance from ELF, will direct the testing and prototyping efforts of Task 3. UND will lead the market analysis and the establishment of ISO compliance in Task 4, with input from ELF.

Project meetings and conference calls with UND and the ELF team will be held on a bi-weekly basis to conduct project activities, review project timelines, evaluate upcoming milestones or deliverables, and discuss the costs and challenges associated with the completion of project tasks. Planning and review meetings or calls with the host sites will be held monthly.

Intellectual property management and discussions have been initiated. During the course of the project, any new findings will be promptly documented, and patent applications will be filed to protect the intellectual property as necessary. Discussions with potential commercial sponsors have been initiated regarding the further development and scale-up of the technology and will be continued on a semi-annual basis as the project progresses.

TIMETABLE

The project has a duration of 16 months, tentatively starting on May 1st of 2021, with the following timetable:

Task ID	Description	Start	Finish	Quarter				
				Q1	Q2	Q3	Q4	Q5
1.0	Project Management and Planning	5/1/2021	9/30/2022					
2.0	On-Site Field Demonstrations	7/1/2021	6/31/2022					
3.0	Research Units Procurement & Fabrication	6/1/2021	8/31/2021					
3.0	Research Units Validation Testing	9/1/2021	6/30/2022					
3.0	Scaled-Down Prototype Fabrication	7/1/2021	9/30/2021					
3.0	Scaled-Down Prototype Testing	9/1/2021	6/30/2021					
4.0	Market Analysis & ISO Compliance	7/1/2021	9/30/2022					
1.0	Final Technical Report	7/1/2021	9/30/2022					

BUDGET

Project Associated Expense	Total Project	NDIC's Share	ELF's Share	NextEra's Share
Personnel	$ 267,270	$ 154,770	$ 112,500	$ -
Travel	$ 29,741	$ 8,862	$ 20,880	$ -
Equipment	$ 68,247	$ 43,247	$ 25,000	$ -
Supplies	$ 10,050	$ 3,800	$ 6,250	$ -

Subcontracts	$ 2,500	$ -	$ 2,500	$ -
Other Direct Costs	$ 4,900	$ 4,900	$ -	$ 100,000
Indirect Cost	$ 101,906	$ 70,656	$ 31,250	$ -
Total cost	$ 584,614	$ 286,234	$ 198,380	$ 100,000
Percent of Total	100%	48.96%	33.93%	17.11%

Personnel salaries are based on the scope of work with actual rates for planned personnel used. NDIC funding will be used to cover UND personnel salary ($154,770), travel ($8,862), equipment ($43,247), miscellaneous supplies ($3,800), analytical costs ($4,900), and indirect costs (F&A of $70,656). At the end of the project, ownership of the ELF research units and prototype will be transferred to ELF Technology, LLC.

Table 1: UND - IES Personnel Salary Including Fringe Benefits

Personnel	**Hours**	**Cost**
Nasah, Project Manager	64	$ 3,942
Nicholas Dyrstad-Cincotta, PI	1387	$ 68,607
Research Engineer	867	$ 36,754
Graduate Researcher	1560	$ 43,491
Resource Manager	64	$ 1,975
Total	3942	$ 154,770

ELF will contribute $198,380, and NextEra will contribute $100,000 of in-kind cost share, bringing private industry investment to 51% of the project's total cost. If less funding is available than the $286,234 requested, the project's scope of work will be revised to reduce Personnel and Equipment costs. Any scope reductions would be applied to the optimization work in Task 3 and the Market Analysis of Task 4 to ensure completion of the field demonstration and scaled-down prototype.

CONFIDENTIAL INFORMATION

No confidential information is included in this report.

PATENTS/RIGHTS TO TECHNICAL DATA

United States Patent Office, patent number 15/894,167.

Note: The reference to the above patent is for full disclosure that a patent exists and was included to inform the Renewable Energy Council.

STATE PROGRAMS AND INCENTIVES

1. Title: Electrostatic Filtration of Large Lubricant Reservoirs, 2/1/2021 – 1/31/2022, $151,494 (NDIC), $351,948 (Total Project).
2. Title: Electrostatic Filtration of Large Lubricant Reservoirs, 10/01/2019- 10/31/2020; $148,000 (North Dakota Department of Commerce), $148,000 (Total Project).

APPENDIX 1

GOVERNING EQUATIONS FOR THE ELF TECHNOLOGY ELECTROSTATIC FILTRATION

Prepared for

ELF Technologies

Prepared by

Shabaz Khan

Nicholas Dyrstad-Cincotta

Institute for Energy Studies

University of North Dakota

August 10, 2020

GOVERNING EQUATIONS FOR THE ELF TECHNOLOGY ELECTROSTATIC FILTRATION

The ELF Technology electrostatic filtration unit's principal action is charging dust particles and forcing these particles to bind to the collecting plate. The technology can be modeled using mathematical operations that are developed from currently existing traditional electrostatic precipitators. Many assumptions were made to understand the theory behind ELF. The simplified design, underlying mathematical equations, assumptions, and calculations are discussed in this paper.

ELF Design

Figure 1 represents a simplified schematic of the ELF unit setup, where positive and negative electrodes, or collection plates, are stacked in an alternating fashion. Figure 2 represents the corona onset and working zone for a typical electrostatic setup.

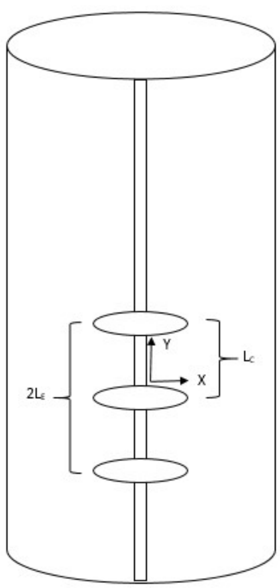

Figure 1: ELF Unit Schematic
L_E= Emitter Electrode Distance
L_C= Collector Electrode Distance

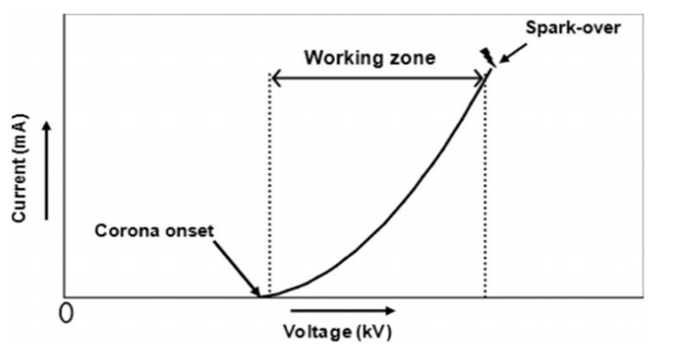

Figure 2: Typical current-voltage curve [1]

The ELF unit functions by having negatively charged emitter plates and positively charged collector plates separated by a nominal distance. Each negative and positive plate is insulated from one another with a layer of foam. Negative voltage is applied, creating a corona field, causing the particles surrounding the plate to form a negative charge. The negatively charged particles are then attracted to the positive plate, where they migrate and effectively bond. Each aspect will be examined in closer detail in the following sections.

Background

The Dielectric strength of the transformer oil is also known as the breakdown voltage. “Breakdown Voltage” (BDV) is measured by observing the voltage required to jump a spark between two electrodes immersed in the oil separated by a specific gap or distance. Also known as the sparking strength, a higher BDV will result in a higher voltage required to jump the spark.

The dielectric strength of the transformer oil is critical since it is essential in maintaining the reliable operation of high-voltage power transformers. The dielectric strength of transformer oil is impacted by the presence of acids, water, and other contaminants. The dielectric strength of oil is susceptible to hydration, or introduction of water and moisture. Under the action of the electric field of the emulsified oil, droplets of water are drawn to places where the field strength is particularly high, which begins the process of oil breakdown. Clean oil with a low moisture content produces higher BDV results than oil with high moisture content and other conducting impurities.

Corona and Electrostatic Precipitation

The voltage applied to the electrodes causes the gas between them to break down electrically, an action known as a "corona." The electrodes are usually given a negative polarity because a negative corona supports a higher voltage than a positive corona before sparking occurs. The ions generated in the corona follow electric field lines from the wires to the collecting plates; therefore, each wire establishes a charging zone through which the particles must pass.

The word "corona" has been used here as a general term that includes any repetitive short-time charge transfer, such as charge injection from electrodes, creepage discharges along dielectric surfaces, and the limited gas-phase discharges often called "partial discharge-PD." It does not include conventional ionic or electron mobility. Corona degradation may lead to voltage breakdown without thermal runaway. Corona can be divided broadly into three types:

1) Directly from an electrode into the surrounding space, usually gas;
2) At the surface of a solid dielectric;
3) Within the volume of a solid dielectric, usually in a four-foot void.

Corona can be characterized as a localized voltage breakdown that takes place repetitively. In the simplest case, with an alternating voltage, a single discharge takes place on each half cycle or every other half-cycle; however, multiple discharges take place. With corona from an electrode into a gas, the repetition rate of the discharge increases with voltage (above an onset voltage, the corona start voltage - CSV). The repetition rate and magnitude are usually high and constant with time unless the corona changes the electrode's characteristics. For surface, and especially for volume corona, the dielectric solid's characteristics may greatly influence both the corona repetition rate and magnitude as a function of time.

Electrical Operating Point and Collection Efficiency

The electrical operating point of an ESP section is the voltage and current value at which the section operates. The best collection typically occurs when the highest electric field is present, roughly corresponding to the electrode's highest voltage. The corona inception voltage is the lowest voltage necessary for forming a corona – the electrical discharge that produces ions for charging particles. The corona inception voltage decreases as the frequency of the applied voltage increases.

The charged dust particles are accelerated towards the collecting electrode using the Coulomb force within the electric field. According to the equation of motion, these particles reach a hypothetical migration velocity dependent on the particle size. For comparatively large particles, greater than 2 µm in diameter, the migration velocity is proportional to the electric field strength squared. For smaller particles, the relationship is only linear. The ''Deutsch'' equation states that a higher migration velocity leads to higher collection efficiency; however, it is influenced by many factors such as electrode geometry and the properties of the dust particles. The effective migration velocity within a precipitator is not equal to the hypothetical migration velocity that can be calculated; therefore, empiricism is involved in modifying the original ''Deutsch'' equation to obtain more precise tools for the dimensioning of ESPs. From the power supply point of view, however, it can be stated that the collection efficiency is proportional to the applied voltage (VESP) squared, and the precipitator current IESP.

It is vital to operate the precipitator at a maximum voltage and provide enough power to drive a sufficiently high corona current to obtain higher collection efficiencies. Filtration speed is increased with an increased number of projections, applied voltage, oil temperature, and decreased electrode spacing [2].

Investigation into Dielectric Breakdown Voltage of Insulating Oil

A dielectric breakdown voltage test measures the electrical stress that an oil can withstand without breakdown. The test can be performed using a test vessel with two electrodes mounted in it and a fixed gap. Sample oil is placed in the vessel, and an AC voltage is applied to the electrodes. The voltage is increased until the oil breaks down, such as until a spark passes between the electrodes. The test method for determining the breakdown voltage can vary based on the size and shape of the electrodes, the gap between them, the rate at which voltage is increased, and whether or not the oil is stirred during the test. A company specializing in power applications, such as Megger, can be utilized to procure standardized test equipment if desired to determine the exact dielectric constant of various new and used oils.

The theoretical dielectric strength of a specific material is an intrinsic property based on the bulk material and is independent of the configuration of the material or electrodes with which it is applied. Because of defects in the dielectric materials, the dielectric strength is typically significantly lower than the intrinsic strength of an ideal, defect-free material. As shown in Table , from the CRC handbook of chemistry and physics, the intrinsic value for the dielectric strength of pure silicon oil is potentially 10-15 kV/mm.

Table 1: Dielectric Strength of Liquids [3]

Material	Dielectric strength kV/mm	Ref.
Helium, He, liquid, 4.2 K	10	9
Static	10	11
Dynamic	5	11
	23	12
Nitrogen, N_2, liquid, 77K		
Coaxial cylinder electrodes	20	10
Sphere to plane electrodes	60	10
Water, H_2O, distilled	65-70	13
Carbon tetrachloride, CCl_4	5.5	14
	16.0	15
Hexane, C_6H_{14}	42.0	16
Two 2.54 cm diameter spherical electrodes, 50.8 µm space	156	17,18
Cyclohexane, C_6H_{12}	42-48	16
2-Methylpentane, C_6H_{14}	149	17,18
2,2-Dimethylbutane, C_6H_{14}	133	17,18
2,3-Dimethylbutane, C_6H_{14}	138	17,18
Benzene, C_6H_6	163	17,18
Chlorobenzene, C_6H_5Cl	7.1	14
	18.8	15
2,2,4-Trimethylpentane, C_8H_{18}	140	17,18
Phenylxylylethane	23.6	19
Heptane, C_7H_{16}	166	17,18
2,4-Dimethylpentane, C_7H_{16}	133	17,18
Toluene, $C_6H_5CH_3$	199	17,18
	46	16
	12.0	14
	20.4	15
Octane, C_8H_{18}	16.6	14
	20.4	15
	179	17,18
Ethylbenzene, C_8H_{10}	226	17,18
Propylbenzene, C_9H_{12}	250	17,18
Isopropylbenzene, C_9H_{12}	238	17,18
Decane, $C_{10}H_{22}$	192	17,18
Synthetic Paraffin Mixture		
Synfluid 2cSt PAO	29.5	37
Butylbenzene, $C_{10}H_{14}$	275	17,18
Isobutylbenzene, $C_{10}H_{14}$	222	17,18
Silicone oils—polydimethylsiloxanes, $(CH_3)_3Si\text{-}O\text{-}[Si(CH_3)_2]_k\text{-}O\text{-}Si(CH_3)_3$		
Polydimethylsiloxane silicone fluid	15.4	20
Dimethyl silicone	24.0	21,22
Phenylmethyl silicone	23.2	22
Silicone oil, Basilone M50	10-15	23
Mineral insulating oils	11.8	6
Polybutene oil for capacitors	13.8	6
Transformer dielectric liquid	28-30	6
Isopropylbiphenyl capacitor oil	23.6	6
Transformer oil	110.7	24
Transformer oil Agip ITE 360	9-12.6	23
Perfluorinated hydrocarbons		
Fluorinert FC 6001	8.0	23
Fluorinert FC 77	10.7	23
Perfluorinated polyethers		
Galden XAD (Mol. wt. 800)	10.5	23
Galden D40 (Mol. wt. 2000)	10.2	23
Castor oil	65	25

Experimental testing performed by Lee et al. reported the dielectric breakdown voltage of pure transformer oil (OT-4) of approximately 10 kV with a gap distance of 1 mm between electrodes and 14 kV for a gap distance of 2.5mm [4]. Prior experimental testing with the Electrostatic Lubricant Filtration (ELF) unit yielded a breakdown voltage of 18kV at a gap distance of 1” (25.4mm).

Governing Equations

The operation of the ELF system can be understood by exploring three key processes:

1. Corona Development
2. Particle Charging
3. Collection efficiency

Corona Development: The key electrical control points for the ELF technology are Voltage and Current. The strength of the corona field depends primarily on these electrical operating set-points. The optimal collection occurs when the highest electric field is present, roughly corresponding to the electrode's highest voltage [5]. The lowest voltage acceptable is the voltage required for the formation of the corona. This applied voltage and current is divided into several parts:

1. Corona onset field at the emitter electrode surface
2. Corona onset voltage
3. Current Density
4. Sparking field strength

Corona Onset Field: The theoretical corona onset filed is calculated through Peek's formula as expressed in Equation (1)[1], [6] :

$$E_c = 3 \times 10^6 f \left[s.g + 0.03 \sqrt{\frac{s.g}{r_c}} \right] \tag{1}$$

E_c = corona onset field at the emitter electrode surface, (V/m)
s.g.= specific gravity of the gas/liquid, relative to air at 293 K and 1 atm
r_c = radius of the wire, m
f = roughness factor (for a clean smooth wire/electrode =1.0; for practical applications= 0.6 is a reasonable value)

Corona Onset Voltage: The voltage that must be applied to the wire to obtain onset field strength is found by integrating the electric field from the wire to the collecting electrode. In cylindrical geometry, the field is inversely proportional to the radial distance. This instance leads to a logarithmic dependence of voltage on electrode dimensions. The corona onset voltage, V_0, is given by [10, 11]

$$V_0 = E_c r_c \ln\left(\frac{d}{r_c}\right) \tag{2}$$

d = outer cylinder radius in a tubular ELF
d = $(4/\pi)L_c$ for plate-wire ELF
L_c= Emitter Electrode-Collector Electrode Distance

The first electrode is charged to a high negative voltage. As particles present in the fluid move past the negatively charged plate, they pick up a negative charge. Higher up the vessel, or further along if it is a horizontal vessel, there is a second electrode consisting of metal plates charged to a high positive voltage and connected to a ground. Since unlike charges attract, the negatively charged particles are attracted to the positively charged plates [7].

Current Density: Until voltage reaches the corona onset voltage, the current does not flow. The vertical electric field strength distribution from the Emitter plate to collector plate can be represented as:

If particle space charge is present [8]:

$$E_y(y) = \sqrt{(E'^2_{ave} + \frac{2J_p}{\epsilon_0\, Z_i}y)} - E'_{ave} \tag{3}$$

If particle space charge is absent [8]:

$$E_y(y) = \sqrt{(E'^2_{ave} + \frac{2J_p}{\epsilon_0\, Z_i}y)} \tag{4}$$

E'_{ave} = Average electrostatic field at plate ($\frac{V}{m}$)
J_p = The average current density at plate ($\frac{V}{m}$)
Z_i = The ion mobility ($\frac{m^2}{V/s}$)
ϵ_0 = Permittivity of space ($\frac{C^2}{N/m^2}$)
y = Distance from centerline

Cooperman and White [8], [9] provided two equations based on an electrostatic field and space charge field strength. From there, which equation to use is based on the assumption of a particle space charge's existence and whether the electrostatic field is uniform.

Without Particle Space Charge

From the Poisson equation, we know [8],

$$\nabla^2 V = \frac{dE}{dx} = \frac{\rho}{\epsilon_0} = -\frac{J_p}{\epsilon_0 Z_i E} \tag{5}$$

This yields,

$$E_y^2(y) = E'^2_{ave} + \frac{2J_p}{\epsilon_0 Z_i} y \tag{6}$$

E'_{ave} is the average electrostatic field and can be determined from Gauss Law to be,

$$E'_{ave} = \frac{\pi r_c E_c}{2L_E} \tag{7}$$

$$= \frac{\pi V_c}{2L_E \ln \frac{r_{cylinder}}{r_{emitter\ electrode}}} \tag{8}$$

The voltage that must be applied to the wire to obtain this field value is found by integrating the electric field from the wire to the collecting electrode.

$$\int_0^{L_c} E_y dy = V \tag{9}$$

$$\int_0^{L_c} E_y dy = (V - V_c) + V_c \tag{10}$$

However, the formula for E_y was derived under the assumption that the system had a uniform electrostatic fieldE'_{ave}; therefore, to maintain the consistency of the approximation, the second term V_c, which represents the electrostatic voltage, must be replaced by$L_c E'_{ave}$.

$$(V - V_c) + L_c E'_{ave} = \int_0^{Lc} E_y dy$$

$$=> (V - V_c) + L_c E'_{ave} = \int_0^{L_c} \sqrt{E'^2_{ave} + \frac{2J_p}{\epsilon_0 Z_i} y} \, \mathrm{dy}$$

$$=> (V - V_c) + L_c E'_{ave} = \frac{Z_i \epsilon_o}{2J_p} . \frac{2}{3} \left[\left(E'_{ave} + \frac{2J_p}{\epsilon_0 Z_i} L_c \right)^{\frac{3}{2}} - E'^3_{ave} \right]$$

$$=> J_p = \frac{\epsilon_0 Z_i}{16 L_c} \left[\alpha + \sqrt{\alpha^2 + 192 (V - V_c)(L_c E'_{ave})^3} \right] \tag{11}$$

Where:

$\alpha = 9(V - V_c + L_c E'_{ave})^2 - 12(L_c E'_{ave})^2$

$E'_{ave} = \frac{\pi V_c}{2 L_E \ln \frac{r_{cylinder}}{r_{emitter\ electrode}}}$

r_c = Radius of the discharge/emitter electrode

L_E = Emitter electrode-Emitter electrode distance

E_c = Corona initiating electric field ($\frac{V}{m}$)

V_c = Corona onset voltage (V)

L_c = Emitter electrode-Collector electrode distance

V = Applied voltage (V)

$r_{cylinder}$ = Cylinder radius

With Particle Space Charge [8]

Then,

$$\frac{dE}{dy} = \frac{J_p}{\epsilon_0 Z_i E} + \frac{\rho}{\epsilon_0}$$

The solution for this is,

$$E_y - \frac{J_p}{\rho Z_i} \ln \left(1 + \frac{\rho Z_i}{J_p} E_y \right) = \frac{\rho}{\epsilon_0} y + E'_{ave} - \frac{J_p}{\rho Z_i} \left(1 + \frac{\rho Z_i}{J_p} E'_{ave} \right) \tag{12}$$

If E_y is the function of J_p and y,

Then,

$$V - V'_c + L_c E'_{ave} + \frac{L_c^2 \rho}{2\epsilon_0} = \int_0^{L_c} E_y dy$$

Here,

$$V'_c = V_c + \frac{L_c^2 \rho}{2\epsilon_0}$$

Where,

ρ = Dust space charge density

Sparking Field Strength [5]:

$$E_s = 6.3 \times 10^5 (\frac{273P}{T})^{0.8} \quad (13)$$

Where,

E_s = Sparking field strength ($\frac{V}{m}$)

T = Absolute temperature, (K)

P = Gas pressure (atm)

Particle Charge:

Particle charging takes place when ions collect on the surface. Once an ion is close to a particle, it is tightly bound because of the image charge within the particle. The image charge represents the charge distortion that occurs when a real charge approaches a conducting surface. The distortion is equivalent to a charge of opposite magnitude to the real one, located as far below the surface as the real charge is above it. The fictitious charge's motion is similar to an image's motion in a mirror, hence the name. As more ions accumulate on a particle, the total charge tends to prevent further ionic bombardment.

There are two principal charging mechanisms: diffusion charging and field charging. Diffusion charging results from the ion's thermal kinetic energy overcoming the ion's repulsion on the particle. Field charging results when ions follow electric field lines until they terminate on a particle. In general, both mechanisms operate for all sizes of particles. Field charging is the dominant mechanism for particles greater than approximately $2\mu m$, whereas diffusion charging dominates for particles smaller than approximately $0.5\mu m$ [10], [11].

The particle charge is a function of particle size and can be described by Cochet's charge equation [12],

$$q = [\,(1 + \frac{2\omega_i}{d_p})^2 + \frac{2}{1 + \frac{2\omega_i}{d_p}} \times \frac{k-1}{k+2}\,]\, \pi\epsilon_0 E'_{ave} d_p^2 \tag{14}$$

Where,

ω_i = Mean free path of the ion
d_p = Particle diameter
$k =$ Dielectric constant of particles
E'_{ave} = Average electric field
ϵ_0 = Permittivity of the free space

Fine particle charge: For fine particles much smaller than the ionic mean free path ($\frac{\omega_i}{d_p} \gg 1$), the equation's second term can be neglected. The positive charge equation is,

$$q_f = (1 + \frac{2\omega_i}{d_p})^2\, \pi\epsilon_0 E'_{ave} d_p^2$$

A further simplification can be made by approximating $(1 + \frac{2\omega_i}{d_p})^2$ to $\frac{2\omega_i}{d_p}$,

$$q_f = 4\omega_i^2\, \pi\epsilon_0 E'_{ave} \tag{15}$$

Coarse particle charge: For coarse particles much larger than the ionic mean free path ($\frac{\omega_i}{d_p} \gg 1$), the value $\frac{2\omega_i}{d_p}$ will be removed from the first and second terms, the particle charge equation,

$$q_c = (2 \times \frac{k-1}{k+2})\, \pi\epsilon_0 E'_{ave} d_p^2 \tag{16}$$

The total particle charge: The particle charge in terms of particle volume (v) over the entire particle size spectrum is a combination of two equations (14) and (15),

$$q = q_f + \frac{q_c}{v^{\frac{2}{3}}}$$

$$q = 4\omega_i^2\, \pi\epsilon_0 E'_{ave} + \left(2 \times \frac{k-1}{k+2}\right) \pi\epsilon_0 E'_{ave} d_p^2\, (\frac{6}{\pi})^{\frac{2}{3}} \tag{17}$$

The effective migration velocity of a particle is,

$$V_e = \frac{qE_cC}{3\pi\mu d_p}$$

$$= \frac{[4\omega_i^2\, \pi\epsilon_0 E'_{ave} + \left(2 \times \frac{k-1}{k+2}\right)\pi\epsilon_0 E'_{ave} d_p^2\, (\frac{6}{\pi})^{\frac{2}{3}}\,]\,(\mathrm{C} + 3.314\,\frac{\omega}{d_p})\,E'_{ave}}{3\pi\mu d_p} \qquad (18)$$

Where,

$C = C^* + 3.314\,\frac{\omega}{d_p}$ $\quad [\,if\ \frac{\omega}{d_p} > 1, then\ C^* = 0.56$

$\qquad if\ \frac{\omega}{d_p}\ \leq 1, then\ C^* = 1]$

ω = Mean free path of gas

Collection Efficiency [12]**:**

$$n = 1 - Exp\,(-\frac{A_cV_e}{Q}) \qquad (19)$$

Where,

Q = Volumetric flow rate of liquid
A_c = Specific collection surface area
V_e = Effective migration velocity

Applied Calculations

Corona onset field:

$$E_c = 3 \times 10^6 f\left[s.g + 0.03\sqrt{\frac{s.g}{r_c}}\right]$$

$$= 2.15 \times 10^6\ V/m$$

Corona onset voltage:

d = outer cylinder radius in a tubular ELF, m	.3
E_c = corona onset field at the emitter electrode surface, (V/m)	2.15×10^6
r_c = radius of the emitter electrode, m	0.2873
V_c = corona onset voltage (V)	

$$V_c = E_c r_c \ln\left(\frac{d}{r_c}\right)$$

$$= 26{,}720 \text{ V}$$

Current density for non-uniform electrostatic field:

V_c = corona onset voltage (V)	26720
V = Applied voltage (V)	30000
ϵ_0 = Permittivity of space ($\frac{C^2}{N/m^2}$)	8.85×10^{-12}
Z_i = The ion mobility ($\frac{m^2}{V/s}$)	1.7×10^{-4}
J_p = The average current density at plate ($\frac{A}{m^2}$)	
L_c= Emitter Electrode-Collector Electrode Distance (m)	0.0127

$$J_p = \frac{9\epsilon_0 Z_i}{8{L_c}^3}(V - V_c)^2$$

$$= 8.9 \times 10^{-3}\ \frac{A}{m^2}$$

Sparking field strength:

P = Gas pressure (atm)	0.68
T = Absolute temperature, (K)	298
E_s = Sparking field strength ($\frac{V}{m}$)	

$$E_s = 6.3 \times 10^5 (\frac{273P}{T})^{0.8}$$

$$= 431{,}424\ \frac{V}{m}$$

Average electric field:

E_s = Sparking field strength ($\frac{V}{m}$)	431,424
K= Constant behave base on back corona	If severe back corona then value 2.50 and no back corona then 1.75

$$E'_{ave} = \frac{E_s}{K}$$

$$= 246528.28\ \frac{V}{m}$$

Total particle charge:

ω_i = Mean free path of the ion (m)	9.71×10^{-8}
d_p = Particle diameter (micron)	2.5×10^{-6}
k = Dielectric constant of particles	2.1
E'_{ave} = Average electric field, V	246,528
ϵ_0 = Permittivity of space ($\frac{C^2}{N/m^2}$)	8.85×10^{-12}
q= Particle charge (C)	

$$q = 4\omega_i^2\ \pi\epsilon_0 E'_{ave} + \left(2 \times \frac{k-1}{k+2}\right)\pi\epsilon_0 E'_{ave} d_p^2\ (\frac{6}{\pi})^{\frac{2}{3}}$$

$$= 3.57\times 10^{-17}\ \text{C}$$

Effective migration velocity of a particle:

q= Particle charge (C)	3.57×10^{-17}
E_c = corona onset field at the emitter electrode surface, (V/m)	$2.15 \times 10^6\ V/m$
Cn= Cunninghum Correction $Cn = C^* + 3.314\ \frac{\omega}{d_p}\ [\,if\ \frac{\omega}{d_p} > 1, then\ C^* = 0.56\ if\ \frac{\omega}{d_p}\ \le 1, then\ C^* = 1]$ ω = Mean free path of gas	1.13
μ= Flow viscosity (kg/m.s)	1.3×10^{-1}
d_p = Particle diameter (micron)	2.5×10^{-6}
V_e = Particle migration velocity (m/s)	

$$V_e = \frac{qE_cCn}{3\pi\mu d_p}$$

$$= 2.83\times 10^{-5}\ (\frac{\mathrm{m}}{\mathrm{s}})$$

Collection Efficiency:

Q = Volumetric flow rate of liquid ($\frac{m^3}{s}$)	5 gallons per minute = 0.00032 cubic meter per second
A_c = Specific collection surface area (m^2)	0.122 square meter (2 collector plate of 11" in diameter)
V_e = Effective migration velocity (m/s)	2.83×10^{-5}
n= efficiency	

$$n = \left[1 - Exp\left(-\frac{A_cV_e}{Q}\right)\right] * 100$$

= 1.03% for 2.5 micron particles and a single plate set

Predicted Performance as a Function of Design

The basis for the above calculation is a particle diameter of 2.5 microns and a two-plate collection area. This setup serves as a basis to explore different design parameters and operational inputs. The following section provides additional insight into how the contaminant's particle size impacts the overall collection, the number of plates, or area, in the system, and the number of cycles to approximate the impact of the oil reservoir size versus the circulation rate through the ELF filter.

Figure 3 displays the relative impact of the impurity particle size on the single-pass collection efficiency, where the single-pass efficiency is defined as the percentage of particles of any given size removed with one pass of the oil through the filter. This instance would represent the case where the oil was cleaned and sent to a separate storage tank, rather than continuously recirculating the oil back into the primary reservoir. The case where the oil is recirculated will be discussed later as related to the number of cycles.

Figure 3 shows that for particles sized at 4-, 6-, 14-, 25-, 38-, and 70-microns and in the same collection area, as the particle size increases, the collection efficiency also increases. This phenomenon is expected based upon theory and is observed in electrostatic filtration devices.

This comparison is based upon the single-pass efficiency and illustrates the impact of particle size rather than the absolute removal expected from the ELF filter.

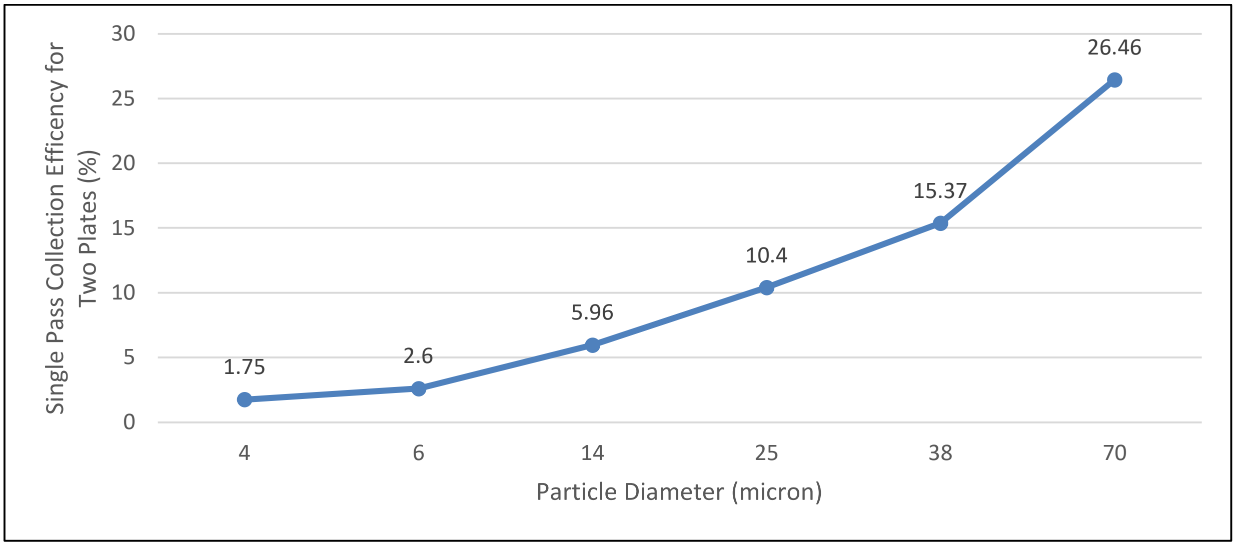

Figure 3: Single-pass collection efficiency for two plates (%) versus Particle Diameter (micron)

The importance of the collection plate's overall area is illustrated in the equation used to calculate the system efficiency. This observation is significant because the ELF filter design is modular, and the collection area can be easily increased during the design by merely increasing the number of plates inside the filter housing. Figure 4 compares the single-pass collection efficiency for six particle-sized and multiple plate-sets ranging from one to nine. As expected, the highest number of collection plates, or maximum area, results in a maximum number of particles for a single pass. As demonstrated before, the larger sized particles are collected at a higher rate than the smaller sized particles. While the magnitude of increase in performance decreases as the number of plates increase, the calculations show there is still an added value of including the nine sets of plates used in the current ELF design.

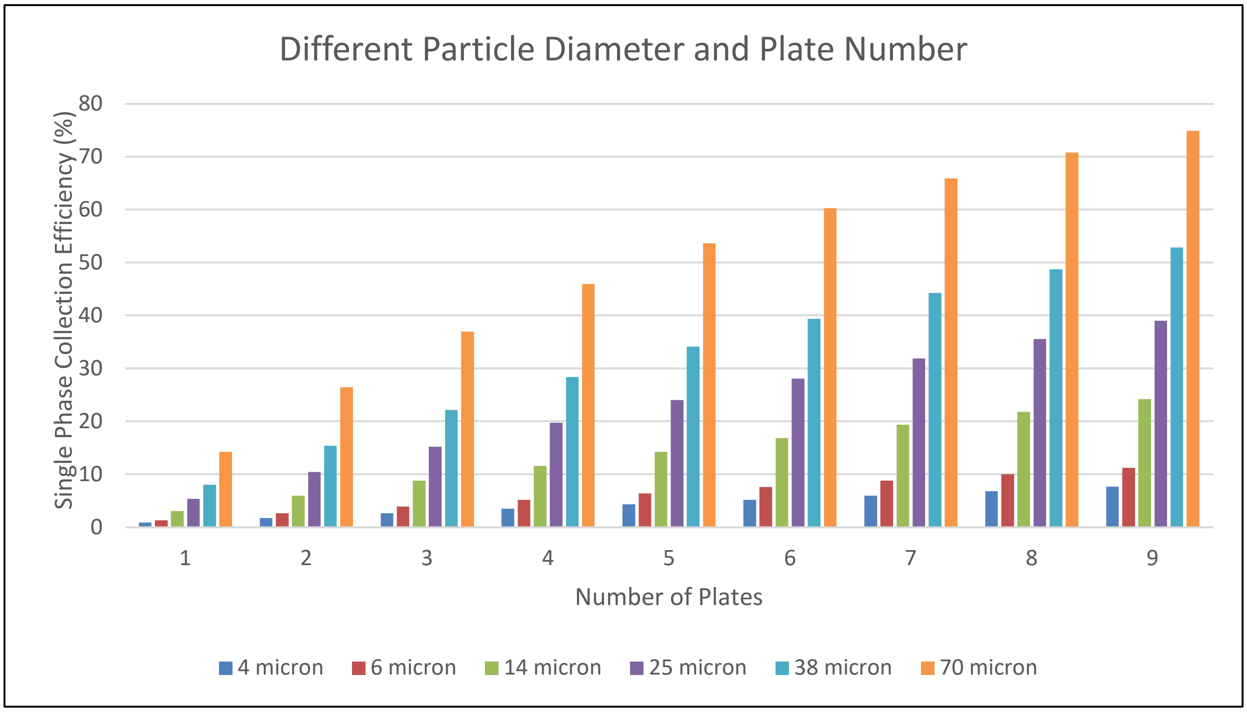

Figure 4: Single-pass collection efficiency for different particle size and plate number

These calculations are based on a single-pass efficiency, where the fluid is treated and not recycled back into the system. In reality, the fluid is returned to the reservoir, mixed with the oil in the system, and continuously re-filtered through the ELF filter. A simple way to represent this is to use the term “cycle” to represent the time when the entire volume of the reservoir is passed through the filter, assuming there is no mixing occurring in the reservoir. This method provides a way to relate the reservoir volume to the filter rate in units of time (reservoir volume/circulation rate). For a reservoir volume of 10,000 gallons and a circulation rate of 5 gpm (7200 gallons/day), one cycle would take 10,000 gallons divided by 7200 gallons/day, or 1.39 days/cycle. If the system was operated for 30 days, the number of hypothetical cycles would be 30 days divided by 1.39 days per cycle, or 21.5 cycles.

Figure 5 discloses the overall collection efficiency as a function of cycle number and, as expected, shows that as the cycle number increases, so does the overall collection efficiency. This finding means that high overall efficiencies can be achieved, even though the single-pass efficiencies are not significantly high. This consideration is vital in the design philosophy of the ELF filter, which allows for a compact design with the relatively low electrical requirements of the ability to achieve optimal performance. Figure 5 also demonstrates the difference in collection efficiency afforded by particle size. Figure 3 shows us three different particle sizes, 4-, 6-, and 14-micron chosen as they represent the three markers for the ISO testing and collection efficiency compared to the cycle numbers. From this figure, we can see that the 14-micron particle took 17 cycles to reach 99% removal, while the 6- and 4-micron sized particles took 39 and 59 cycles to achieve the same near-pristine state. The time required to achieve this number of cycles is controlled by the variance of the reservoir size and filter circulation rate, which will be demonstrated from real data collected in the field and can be accomplished in a reasonable amount of time.

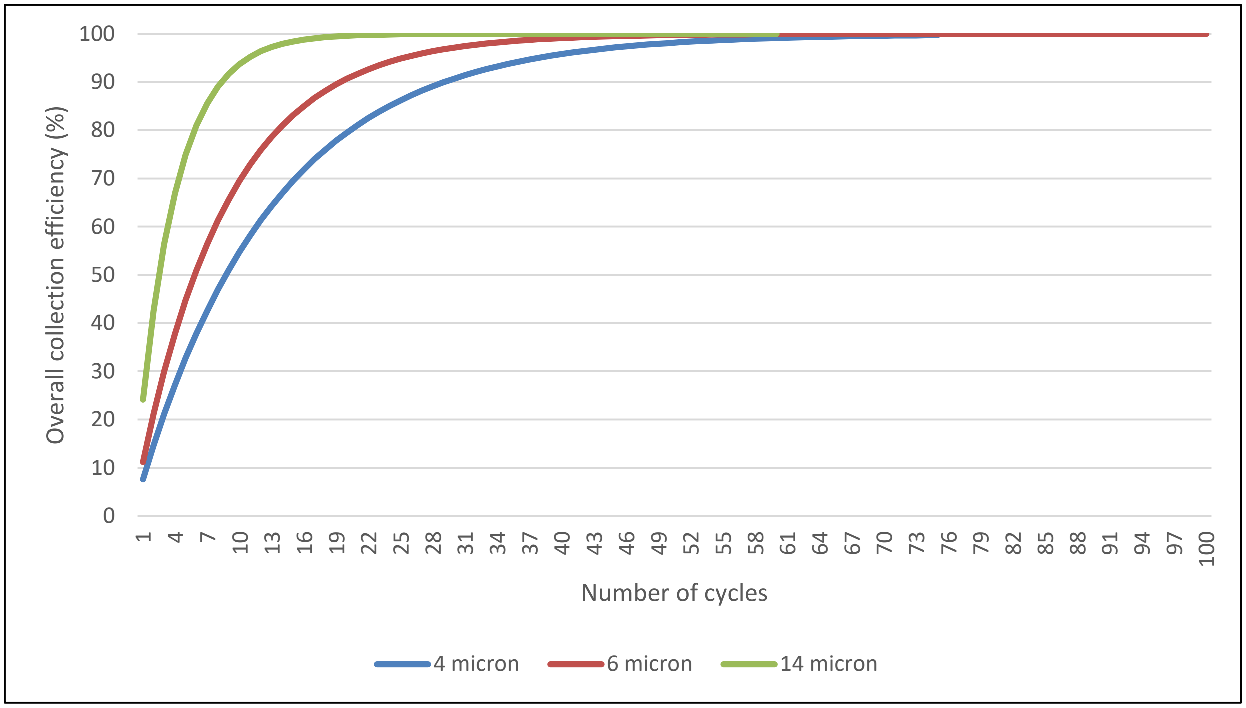

Figure 5: Overall collection efficiency relation with three different particle size and cycle number

The data in Figure 5 displays the case for three different mono-sized particle distributions. In reality, the system will contain a distribution of many different sized particles; therefore, the actual relationship between cycle number (time) and removal efficiency will vary depending upon that distribution. If we take an arbitrary size distribution of 50% - 4 micron particles; 20% - 6 micron; 5% - 14 micron; 5% - 25 micron; 10% - 38 micron particle, 10% - 70 micron particles, the ELF system would take 51 cycles to reach 99% collection efficiency with 9 collection plates (Figure 6). This illustration closely represents how the system would behave in the real-world.

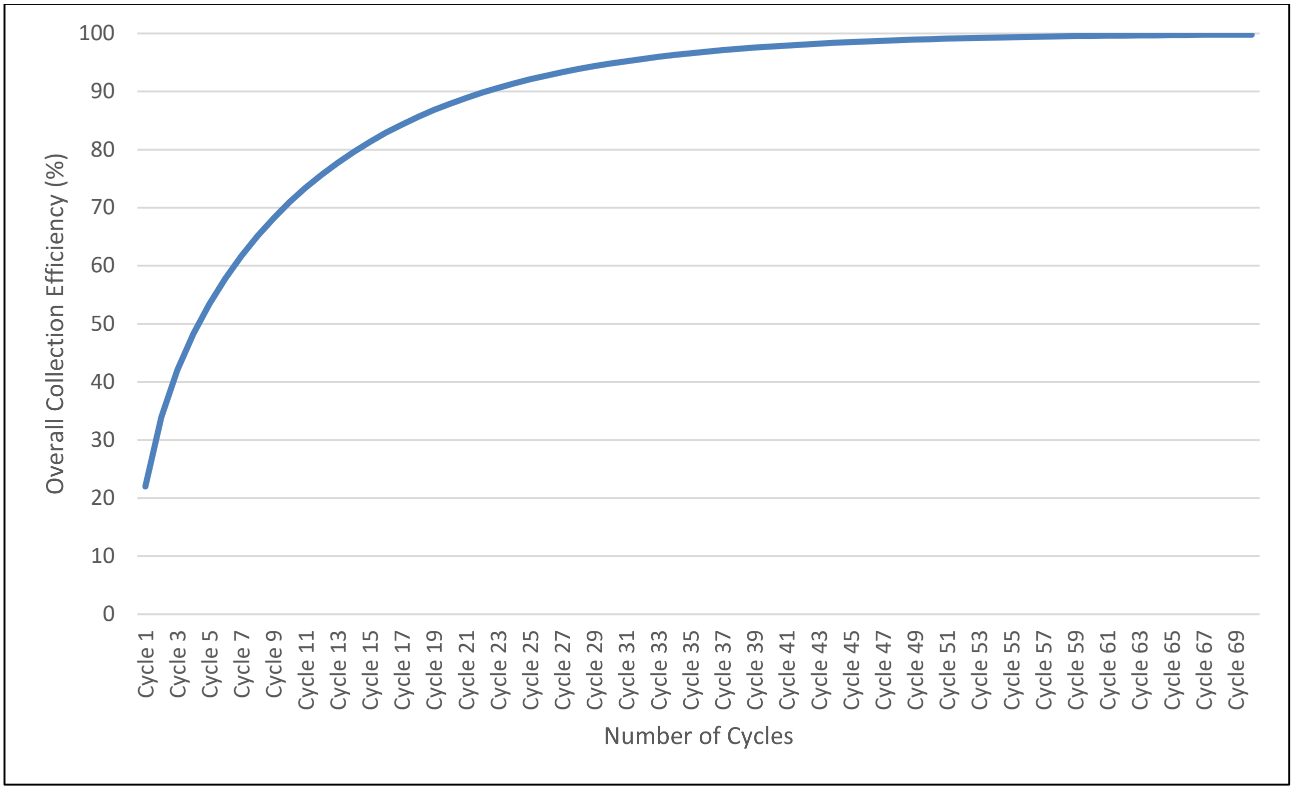

Figure 6: Overall collection efficiency relation with cycle number for combinations of different particle size

Field Data

Modeling efforts are essential in that they can help drive design decisions and demonstrate the potential for a device to accomplish the design objective; however, to have value, the model must show similar trends as observed in the field. ELF Technologies recently completed two field tests with its larger units, the unit located at the Leland Olds Station and the unit located at the Coyote Station, which are both lignite-fired electric generating plants located in North Dakota. The Leland Olds plant has a reservoir size of 12,000 gallons and had starting particle counts of 9,030, 2,180, and 390 for the 4-, 6-, and 14-micron sizes, respectively. In contrast, the Coyote plant has a 4,500-gallon reservoir and had starting particle counts of 1,250, 520, and 80 for the 4-, 6-, and 14-micron sizes, respectively. Figures 7 and 8 show that high removal efficiencies were obtained in both cases, demonstrating the same trend versus time as predicted in the hypothesis developed here. In both field tests, the circulated oil particle counts had been reduced to levels equivalent to pristine oil by the end of the testing.

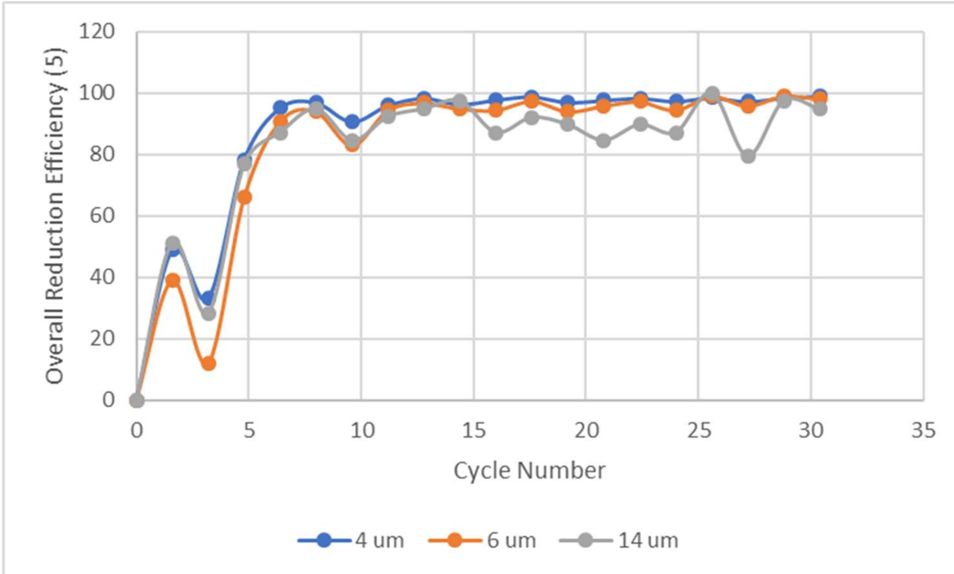

Figure 7. Reduction of particle counts for the field test at the Leland Olds Station

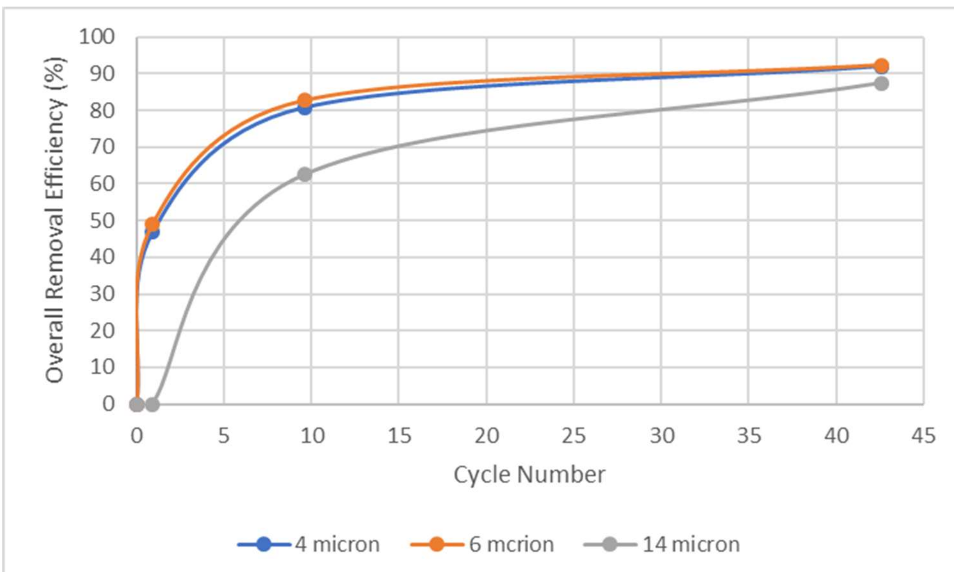

Figure 8. Reduction of particle counts for the field test at the Coyote Station

Conclusion

The ELF technology is novel, with limited research and mathematical models available to reference. The idea of using ESP technology with a fully liquid media has not been fully explored. Many assumptions were required to relate to particle charges, corona onset voltages, and field strengths. The mathematical calculations demonstrate the potential of this approach to remove metal impurities from an oil. Results from hypothetical calculations are reinforced with field testing, which shows trends that are in agreement with the calculations provided in this paper.

Recommendations/Future Work

For maximum filtration efficiency, the technology should be operated at maximum voltage, with minimum electrode spacing and a substantial number of projection points. Experimental work at the University of North Dakota Institute for Energy Studies will close the gaps in knowledge and add to the database of information available to provide a robust validation of the equations presented here. The assumptions and equations used herein will be refined where needed based upon additional information collected during field trials.

Prior experimental work completed at the Toyohashi University of Technology in Japan suggests that the optimal variable set points for peak filtration are as follows:

1. Density of Projections
2. Electrode Spacing
3. Applied Voltage
4. Oil Temperature

Our work would follow similar parameters and explore the impacts on the electrostatic lubrication filtration efficiency to continue refinement and miniaturization of the technology.

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APPENDIX 2: FACILITIES & EQUIPMENT

EQUIPMENT:

Field Emission Scanning Electron Microscopes (FE-SEM)

The FEI Quanta 650 FEG SEM is located at the Material Characterization Lab (MCL) at UND. This Field emission SEM is capable of obtaining high-resolution data from almost any sample material. The instrument is operable in both high and low vacuum modes. The x-ray microanalysis system consists of an energy dispersive Bruker QUANTAX 200 x-ray detector. The system is equipped with backscattered and secondary electron imaging. The backscattered imaging allows for discerning materials based on atomic number. The presence of higher atomic number materials increases the brightness and allows for easy identification and subsequent analysis. The instrument can achieve 1-3 nm resolution. The imaging software package allows for performing an analysis of mineral association with coal and other minerals.

Hitachi SEM 3400N with an Energy Dispersive System (SEM/EDS)

The Hitachi 3400N SEM is also located at the Material Characterization Lab (MCL) at UND and is equipped with backscattered and secondary electron detectors for imaging and is automated with energy dispersive x-ray detectors for chemical composition analysis. The system can perform computer-controlled scanning electron microscopy (CCSEM) of particles to determine the size, composition (major, minor, trace elements), and mineral typing. The system is also equipped to provide microstructure analysis and elemental composition information on the association of minerals with coal particles.

X-ray Fluorescence Spectrometers (XRF)

Located at the Material Characterization Lab (MCL) at UND, this Rigaku Supermini 200 XRF is a wavelength dispersive bench-top XRF able to provide low ppm detection limits for major, minor, and trace elements. The instrument is equipped with a 12-sample auto-sampler and can analyze either solids or liquids. The software allows rapid analysis of known and unknown samples. The system provides the ability to perform quantitative analysis and qualitative survey scans to identify the presence of elements.

X-ray Diffraction (XRD)

Located at the Material Characterization Lab (MCL) at UND, the Rigaku SmartLab is a fully automated XRD that utilizes crossbeam optics (CBO), enabling fast and easy changing of the incident X-rays by substituting selection slits. The instrument can operate in either Bragg-Brentano or parallel beam focusing methods. The flexible design allows for the analysis of samples ranging from loose powder to large sample pieces. The instrument is equipped with a scintillation acquisition. A Cu $K\alpha_1$ system with a monochromator is also available for high-intensity measurements. The system is equipped with a CCD camera for imaging specific areas on a sample and has various stages allowing analysis of a wide array of sample types and applications. Once the x-ray diffraction pattern is obtained, it is analyzed to determine the crystalline phases present. The system can also be used to perform quantitative XRD analysis.

Raman Spectrometer

This Thermo Scientifics' Nicolet NXR 9650 FT-Raman spectrometer is located at the Chemical Engineering Department at UND's College of Engineering and Mines. It can produce high-quality Raman measurements using high-speed scanning, sample mapping, screening applications, and kinetic analysis. This Raman Spectrometer can measure organic and inorganic samples using a spectral range down to 100 cm^{-1}, which is advantageous for inorganic samples where bands are typically observed at low frequencies. The confirmation of graphene will be performed by the Raman Spectrometer.

High Resolution of Transmission Electron Microscope (HR-TEM)

This JEOL JEM-2100 multipurpose analytical high-resolution transmission electron microscope system is located in the Electron Microscopy Center at North Dakota State University, which is only 70 miles away from UND. Being an A-12 a member of the North Dakota University System (NDUS) with NDSU, UND users have access to this equipment at a favorable price. HRTEM is a powerful tool to study properties of materials on the atomic scale, such as semiconductors, metals, nanoparticles, and *sp*2-bonded carbon (e.g., graphene, C nanotubes). At present, the highest point resolution realized in phase contrast TEM is approximately 0.050 nm.

Zetasizer Nano ZS90 (Malvern Instruments Ltd, UK)
This equipment is available at the Chemistry Department at UND. It is a Dynamic Light Scattering (DSL) system for the measurement of particle size and molecular size at a 90-degree scattering angle using Dynamic Light Scattering, and the ability to measure zeta potential and electrophoretic mobility using Laser Doppler Microelectrophoresis, and molecular weight using Static Light Scattering. Using 90-degree scattering optics, it allows for size measurement from 0.3nm (diameter) to 5 microns and molecular weight measurements down to 9,800Da.

Carbon Analyzer TOC SSM 5000A analyzer (Shimadzu, Japan)
This equipment is located at the Environmental Analytical and Research Laboratory (EARL) at UND. Total carbon (TC), inorganic carbon (IC), total organic carbon (TOC) analyses via Shimadzu TOC Analyzer and SSM-5000A Solid Sample Module in both aqueous and solid samples as well as total nitrogen analyses via TNM-1 Unit in aqueous samples. The carbon content of LFP/G will be tested by this carbon analyzer.

Sample Preparation
To take advantage of the above equipment, UND has a fully-equipped sample preparation lab, with all of the necessary capabilities for the sample preparation requirements contained in the proposed project. Available equipment includes a Mixer/Mill 8000 M (SPEX, USA), a LaboPol-21 polisher (Sturers Inc.), an X-press sample presser (SPEX, USA), a K-1 flux (SPEX, USA), a shatter box (SPEX, USA) and a Micronizing mill (McCrone).

MBraun LABstar MB10 Glove Box: This equipment is a glove box workstation capable of automatically maintaining a clean atmosphere of inert gas with less than 1ppm O_2 and H_2O. The workstation was purchased in 2010, then refurbished and certified by an MBraun technician in 2017. The equipment scrubs O_2 and H_2O with a single column, a regenerable catalytic bed of copper catalyst, and a mole sieve. It is capable of maintaining atmospheres of nitrogen, argon, and helium. An atmosphere of ultra-pure argon is used for lithium-ion battery cell assembly to prevent the reaction of N_2 with the pure lithium counter electrodes.

Kejia KJ-A1200-27L Atmosphere Furnace: Kejia's atmosphere furnace can reach 1200˚C with a 1100˚C working temperature using a 35-step programmable temperature controller. The chamber size is 27 liters and holds a vacuum down to -85 KPa_{gauge} and pressure up to 80 KPa_{gauge}. The chamber can be filled with any desired atmosphere after applying vacuum and filling cycles to achieve a pure working atmosphere. It uses one-way inlet and outlet ports to allow for excess pressure relief without contaminating the atmosphere.

FACILITIES:

Materials Characterization Lab (UND)
The MCL was established to support UND research and educational activities, support industry research and sample analysis needs, and serve as a regional satellite lab. The laboratory is supported by experienced technicians and analytical chemists and has a vast array of analytical equipment and capabilities, including SEMEDAX, XRF, XRD, and TGA. The MCL will be used to examine the OC particle morphology, composition, and determine particle-size distribution.

Institute for Energy Studies Lab

This lab is located on the second floor of the newly built Collaborative Energy Complex at the UND College of Engineering and Mines. It houses a standard chemical fume hood, a walk-in fume hood, an MBraun LABstar MB10 Glove Box, a Kejia KJ-A1200-27L Atmosphere Furnace, and ancillary equipment to support research projects.

Environmental Analytical Research Laboratory (EARL)

UEARL is located on the 3rd floor of Leonard Hall on the UND campus and houses some advanced analytical instruments, including a DIONEX DX-120 Ion Chromatograph (IC), a SOLAAR M6 Atomic Absorption Spectrometer (AAS), a SHIMADZU Total Organic Carbon Analyzer (TOC), a LECO SC-432DR Total Sulfur Analyzer, and ancillary equipment to support teaching, scientific research, and engineering design projects.

Appendix 3: Resumes of Key Personnel

JUNIOR NASAH, M.S.

Major Projects Manager, Institute for Energy Studies

University of North Dakota

Education and Training

University of Buea, Cameroon	Chemistry	B.SC 2007
University of North Dakota	Chemical Engineering	M.S. 2012

Research and Professional Experience

2019-Present Major Projects Manager, UND Institute for Energy Studies.

2012-2018 Research Engineer, UND Institute for Energy Studies

2009-2012 Research Assistant, UND Department of Chemical Engineering

2009 Quality Assurance and Control Assistant, Fermentations Cameroon

Publications (Selected)

- Srinivasachar, S., **Nasah, J.**, Laudal, D. “Mitigation of Aerosol Emissions from Solvent-based Post-Combustion CO2 Capture Systems.” US Department of Energy Agreement No. DE-SC0015737. April 2017.
- **Nasah, J.,** Jensen, B., Dyrstad-Cincotta, N., Gerber, J., Laudal, D., Mann, M., Srinivasachar, S. “Method for Separation of Coal Conversion Products from Oxygen Carriers.” International Journal of Greenhouse Gas Control. Volume 88, July 2019, Pages 361-370.
- **Nasah, J.**, Srinivasachar, S., Laudal, D., Feilen, H. “Method for Separation of Coal Conversion Products from Sorbents/Oxygen Carriers.” Proceedings, International Pittsburgh Coal Conference, 2017.
- 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.

Synergistic Activities

Principal areas of expertise are advanced combustion systems, emissions control for advanced and traditional coal power generation. He has specific expertise on fluid-bed based technology development, leading the development effort for all fluidized bed systems of the CLC group. He has extensive experience in emissions monitoring at bench, pilot, and field scale, and has performed multiple combustion-based testings for technology development or verification.

Other areas under which Mr. Nasah has been active include coal-based pollution measurement and control (sulfur oxides, aerosol formation and nitrogen oxides), underground coal gasification, coal beneficiation, and natural gas processing. Mr. Nasah has over five years’ experience in particulate sampling at coal-fired power plants as well as project planning, management, reporting, and day-to-day activities associated with bench-scale research programs.

Nicholas Dyrstad-Cincotta
Engineer
Institute for Energy Studies

2844 Campus Rd, Stop 8153
Grand Forks, ND 58202-8153

Education and Training

University of North Dakota	Mechanical Engineering	B.S. 2018
University of North Dakota	Mechanical Engineering	M.S. 2018

Research and Professional Experience

2018-Present Engineer, UND Institute for Energy Studies.

Currently, Mr. Dyrstad-Cincotta is the lead researcher and experimentalist at the Institute for Energy Studies for the development of a bench-scale Solar Desalination water treatment project called, "Supercritical Water Extraction – Enhanced Targeted Recovery (SWEETR™)." Additionally, he was the lead experimentalist of the previous lab-scale Phase I Supercritical Treatment Technology for Water Purification project at UND. Mr. Dyrstad-Cincotta had a major role in designing, fabricating, operating, programming, and reporting for both of these supercritical water projects. Development was based on experience gained over several years of working on high temperature and pressurized systems with mentoring from experts in developing advanced energy systems. Mr. Dyrstad-Cincotta also served as the technical lead on the North Dakota Department of Commerce funded project: Electrostatic Lubrication Filtration (ELF).

Mr. Dyrstad-Cincotta's other responsibilities include identifying, developing and executing research projects specifically in water treatment, carbon capture, and air pollution control from energy-based sectors. Mr. Dyrstad-Cincotta was one of the lead technology developers in the Institute for Energy Studies Chemical Looping and Combustion (CLC) group. He was a key developer of a char separation technology to segregate fuel combustion products (char and ash) from oxygen carriers and a key researcher in the development and testing of the newly awarded Spout-Fluid Bed – based CLC technology. His development includes integration of the char separation technology and the novel spout fluidized bed system for the CLC. Mr. Dyrstad-Cincotta assists in the development of new oxygen carriers, reactor vessels, and non-mechanical flow control valves for the new CLC system.

2016-2018 Junior Engineer, UND Institute for Energy Studies.

Key developer and a lead experimentalist for the Phase II continuation of the High-Capacity Sorbent and Process for the CO_2 project - Enhanced Capture of CO2 with Hybrid Sorption: E-CACHYS™ bench scale project. Additional responsibilities include process and mechanical design, fabrication, programming, and operation of the several research projects awarded to the University of North Dakota – Institute for Energy Studies.

2015 Quality Engineering Co-op, United Technology Corporations Aerospace Systems.

Gained extensive knowledge in quality engineering, lean manufacturing, and product/process design. In this role, he delivered quality controls and enhancements to proactively address problems and improve product quality, manufacturing flow, customer satisfaction, and bottom-line results. His responsibilities included verifying the quality and performance of the products in addition to troubleshooting the rectification of any existing errors or defects through product failure mode effects analysis (PFMEA). Additionally, Mr. Dyrstad-Cincotta worked to improve the efficiency of production operations, prepare engineering drawings in AutoCAD, ensure ISO compliance, and managed the engineering change process.

2013-2016 Research Assistant, UND Institute for Energy Studies.

Researched and developed several sorbent-type technologies, such as Sorbents for the capture of post-combustion CO_2 from coal-fired power plants. He was key personnel for implementing Capture from Existing Coal-Fired Plants by Hybrid Sorption Using Solid Sorbents Capture CACHYS™ technology - a High Capacity Sorbent and Process for CO_2 Capture lab-scale project awarded in 2013.

Selected Publications/Presentations

Tomomewo, O. S., **Dyrstad-Cincotta, N**., Mann, M. D., Ellafi, A., Alamooti, M., Srinivasachar, S., & Nelson, T. "Proposed Potential Mitigation of Wastewater Disposal Through Treated Produced Water in Bakken Formation." American Rock Mechanics Association., September 2020.

Dyrstad-Cincotta, N. "Supercritical Treatment Technology for Water Purification." North Dakota Energy Conference & Expo (NDECE), Grand Forks, ND. November 2019.

Mann, M. D., Srinivasachar, S., **Dyrstad-Cincotta, N.** "Supercritical Treatment Technology for Water Purification." U.S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) Concentrating Solar-Thermal Power (CSP) Program Summit 2019, Oakland, CA. March 2019.

Nasah, J., Jensen, B., **Dyrstad-Cincotta, N.**, Gerber, J., Laudal, D., Mann, M., Srinivasachar, S. "Segregation of Unreacted Char from Oxygen Carriers During Chemical Looping Combustion." 5th International Conference on Chemical Looping, 24-27 September 2018, Park City, Utah, USA.

Nasah, J., Gerber, J., Laudal, D., Mann, M., Srinivasachar, S., **Dyrstad-Cincotta, N.**, Jensen, B. "Method for Separation of Coal Conversion Products from Oxygen Carriers." Journal, International Journal of Greenhouse Gas Control. 2019.

Synergistic Activities

Mr. Dyrstad-Cincotta's principal areas of expertise are emissions control for advanced and traditional coal power generation and supercritical water treatment systems. He has specific expertise on fluid-bed based technology development, aiding in the development effort for all fluidized bed systems of the CLC group. Other areas under which Mr. Dyrstad-Cincotta has been active include coal-based pollution measurement and control (sulfur oxides, aerosol formation, and nitrogen oxides), underground coal gasification, coal beneficiation, and natural gas processing. Mr. Dyrstad-Cincotta has several years' experience in planning, executing, and reporting of activities associated with lab and bench-scale research programs. He is also currently the lead programmer for process control systems (PCS) at the Institute for Energy Studies and has taken on the role of aiding the rest of the UND College of Engineering & Mines in their PCS design and programming efforts.

JAMES KEVIN RICKSON CV

From 2015 through the present, Mr. Rickson has been solely focused on developing and bringing the Electrostatic Lubricant Filtration (ELF) technology to market. In 2018, ELF Technology, LLC was formed, and entered into a partnering agreement with the University of North Dakota, Grand Forks (UND), Center for Innovation in 2019. This partnership was formed to modify and perfect the ELF technology for wind turbine applications, as well as others. Demonstrations and verification deployments have been run at the Otter Tail, Coyote Power Generation plant in Beulah, ND, and a white paper was produced under the auspices and oversight of the UND School of Engineering to document the veracity of the technology. At this time, ELF continues to work with UND School of Engineering to refine and implement a particle sensing technology to augment the efficiencies of the machines.

From 2010 through 2015, Mr. Rickson was a principal in The One Tree Group, LLC. (OTFG). OTFG worked to connect institutional investors to projects looking for long term funding. The client and investor base was international in scope, and OTFG concentrated on projects from $50 million to over $1 billion. It was during this timeframe that Mr. Rickson became acquainted with the Electrostatic Lubricant Filtration technology. The technology was so disruptive that Rickson formed a new company and, over time, concentrated his focus and efforts to bringing this filtering solution to market.

Previous life experiences and work credentials:

As Executive Vice President of International Development for Al Ahli Group, Dubai, Rickson was the point person for the development of the 1.3 million sq. ft. Dubai Outlet Mall. Rickson oversaw the design, construction, and eventual opening at a 95% leased facility, handling all marketing and leasing decisions. James was instrumental and the first international executive to acquire a multi-country entertainment licensing deal for one of the most coveted entertainment brands outside of North America. Jim was the lead negotiator as it related to the acquisition of the Nickelodeon brand for theme park rights through the parent company of Viacom and MTVN. Jim helped lead the detailed creative process for the Marvel Studio Park in Dubai and other major attractions and retail venues with Dubai's most prestigious developer, Nakheel, the developer of the Palm Islands. Projects under this development agenda were valued in excess of $2 billion USD.

In addition, Rickson spent 3+ years working closely with government, NGOs and private developers throughout the peninsular of South Korea. Beginning with the $1.4 Billion USD Marvel Studios Theme Park in Busan, Korea, and subsequently working with Gale International in Incheon, Korea, Dreamwood, Hallyuwood, Robotland, Lippo Group, and a host of other entities on their IP themed entertainment venues throughout the peninsula. Each of these developments incorporated a Hollywood themed entertainment venue within a more significant premium Outlet mall development. Developed and maintains an extensive gaming network, local IP holders, legal, PR, Banking, Interpreter, competitive retail environments, and potential staff to draw from. Rickson has accumulated a wealth of knowledge about the culture, business environment, financial system, and Chinese and Korean mindset towards foreign involvement and Foreign Direct Investment in the Middle and The Hermit Kingdoms.

As Managing Director of S&B International, based in Dubai, United Arab Emirates, James's background was further cultured in international alliances that spanned from Eastern Europe to the rim of Asia Pacific Region. James opened international distribution and branding offices for S&B International in 17 foreign countries throughout this region, negotiating licensing agreements with foreign multi-national companies to represent the American Fortune 1000 corporations under master licensing agreement such as Anheuser Busch, Hershey's Chocolate, Estee Lauder General Foods, General Mills, Martin Emprex, Dunn Stores (Ireland), Marks & Spencer (UK), Jovan Fragrances, Clinique, and many more. James went on to assign his teams in the creation of all globally compliant marketing plans, sales forecasts, opening orders, and inventory tracking systems for these new agents. Negotiated vendor agreements both nationally and internationally.

Formed Middle East Oil Recovery Services, LLC. in Bahrain and worked extensively through Kuwait and the greater Middle East and North Africa (MENA) after the conclusion of the 1st Gulf War.

Formed a joint venture (Institutional Assets, Ltd.) with the Mutual Life Insurance Company of NY (MONY), owned 24.5%, and managed 1 million sq. ft. development in Kansas City, Mo. In addition, the JV established relationships with local developers and participated in extensive retail projects throughout the metropolitan area.

As Vice president of Corporate Affairs for Executive Hills, Inc. Rickson acquired an extensive negotiation background and experience with zoning applications, staff reviews, environmental overview, and council approval. Project management over design development of $300 Million, 1 million sq. ft Kansas City Place office tower and 600,000 Kansas City Merchandise MART projects with PBNA Architects and HNTB Architects. Worked with REITs and Insurance companies on construction and end loans and handled purchases and sales from and to institutional investors.

Handled all lease negotiations for 5 million sq. ft. of office and retail space combined with extensive warehouse development. Clients included Apple Computer, Black & Veatch Engineers, Federal Express, and Sprint et al.

Negotiated construction and end loans with Institutional investors such as Mutual of N.Y. (MONY), Travelers, Teachers' Pension Fund, Aetna, Equitable, and The Morgan Banking Consortium. Also drafted sales and loan agreements with Shook-Hardy- Bacon, and Schuggart-Thompson law firms and designed and initiated global leasing structures for these projects.

Joined Gulf Oil, Corp. as a land agent and negotiated mineral interest rights for Gulf Mineral Resources, Inc. throughout the oil & gas fields and coal substrata across the United States.

EDUCATION:

Bachelor of Science, Management and Finance University of Missouri, Kansas City
30 hours of MBA work, Strategic Planning at University of Missouri, Kansas City
Petroleum Institute of America, Landman's certification in negotiation strategies
Petroleum Institute of America, Title abstracting certification
Real Estate Broker's or Agent's license in Minnesota, Kansas, and Missouri
Member National Association of Real Estate Investment Trusts (NAREIT)

ELF Technology, LLC.
4200 James Ray Dr.
Grand Forks, North Dakota 58202

Nicholas Dyrstad-Cincotta
Institute for Energy Studies
University of North Dakota
Grand Forks, North Dakota

Re: Support Letter for the UND-led Proposal Entitled: "Electrostatic Lubrication Filtration of Wind Turbine Oil Reservoirs"

Dear Nicholas,

ELF hereby agrees to enter into and participate financially in The Renewable Energy Program to further develop the ELF technology for the wind turbine community in North Dakota.

Having obtained substantial written commitment from NextEra Energy, Inc., a world leader in wind and renewable energy generation, we are anxious to begin the next phase of development and to prove out the long-term value proposition and how deployment of this technology can greatly reduce the operating budgets of wind turbines. We are excited to provide real time data to enhance operational decision making and to develop a scaled technology to meet the many unique needs that NextEra Energy and the renewable energy industry has.

ELF agrees to contribute $198,380 of in-kind cost share as detailed in the table below.

Budget Category	ELF
Personnel	$ 112,500.00
Travel	$ 20,880.00
Equipment	$ 25,000.00
Supplies	$ 6,250.00
Subcontracts	$ 2,500.00
Other Direct Costs	$ -
Indirect Cost	$ 31,250.00
Total cost	$ 198,380.00

Thank you for the opportunity to participate in the North Dakota renewable energy industry in partnership with the University of North Dakota - Institute for Energy Studies.

Most Sincerely,

James K. Rickson
President & CEO
ELF Technology, LLC.
jim@elftechnologyllc.com

January 22, 2021

Mr. Nicholas Dyrstad-Cincotta
M.Sc., Mechanical Engineering
Engineer, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support Letter for the UND-led Proposal Entitled: "Electrostatic Lubrication Filtration of Wind Turbine Oil Reservoirs"

Dear Mr. Nicholas Dyrstad-Cincotta:

I serve as Director of External Training Initiatives with NextEra Energy, Inc. (NYSE: NEE). NEE is the world's largest generator of renewable energy from the wind and sun, as well as a world leader in battery storage. NEE has consolidated revenues of approximately $17.5 billion, approximately 46,400 megawatts of generating capacity, including megawatts associated with non-controlling interests related to NextEra Energy Partners, LP (NYSE: NEP), and approximately 15,000 employees in 30 states and Canada.

This letter expresses our support for your project titled "Electrostatic Lubrication Filtration of Wind Turbine Oil Reservoirs". This proposal is in direct alignment with our company's goals to extend operations between down-times and decrease overhead through adopting your novel oil filtration technology.

We understand the technology is based upon extending the lifetime of turbine lubrication through electrostatic precipitation and is currently in the process of scale-up/commercialization. This effort is of interest to NextEra Energy for reducing down-time of equipment. We agree to support the project with up to $100,000.00 of in-kind expenses, including: i) offering our facility to host a field demonstration, ii) Assistance with oil sampling and analysis, and iii) engineering support given through technology review in teleconference and in-person meetings. We also agree to send samples for analysis according the sampling protocol established by UND for the length of the field demonstration.

We look forward to working with the UND team on this exciting opportunity. If you have questions or require additional information, please do not hesitate to contact me at the letterhead address.

Sincerely,

James H. Auld, J.D.
Director, External Training Initiatives
James.Auld@nexteraenergy.com
(561) 315-2284

UNIVERSITY OF NORTH DAKOTA

UND.edu

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UND.edu/research

January 29, 2021

Karlene Fine, Executive Director
North Dakota Industrial Commission
State Capitol – 14th Floor
600 East Boulevard Avenue
Bismarck, ND 58505-0840

Subject: Tax liability pertaining to UND's proposal, "Electrostatic Lubrication Filtration of Wind Turbine Oil Reservoirs"

Dear Ms. Fine:

I am writing to you regarding the Tax Liability Statement which is a requirement for the University of North Dakota's proposal to the NDIC Renewable Energy Council. Nicholas Dyrstad-Cincotta is the UND Principal Investigator for this proposal entitled "Electrostatic Lubrication Filtration of Wind Turbine Oil Reservoirs." As an Authorized Official of the University of North Dakota, I affirm that the University of North Dakota is a State entity and has no tax liability.

Please feel free to contact me at (701) 777-2505 or Karen.katrinak@und.edu with any questions.

Thank you for the opportunity to propose this project to the Renewable Energy Council.

Sincerely yours,

Karen Katrinak

Karen Katrinak, Ph.D.
Proposal Development Officer
Research and Sponsored Program Development

BUDGET JUSTIFICATION

The following table gives the summary of the total project budget and the requested funding for each of the cost share partners.

Project Associated Expense	Total Project	NDIC's Share	ELF's Share	NextEra's Share
Personnel	$ 267,269.78	$ 154,770	$ 112,500.00	$ -
Travel	$ 29,741.60	$ 8,862	$ 20,880.00	$ -
Equipment	$ 68,247.00	$ 43,247	$ 25,000.00	$ -
Supplies	$ 10,050.00	$ 3,800	$ 6,250.00	$ -
Subcontracts	$ 2,500.00	$ -	$ 2,500.00	$ -
Other Direct Costs	$ 4,900.00	$ 4,900.00	$ -	$ 100,000.00
Indirect Cost	$ 101,905.86	$ 70,656	$ 31,250.00	$ -
Total cost	$ 584,614	$ 286,234	$ 198,380	$ 100,000
Percent of Total	100%	48.96%	33.93%	17.11%

Personnel salary are based on scope of work with actual rates for planned personnel used. NDIC funding will be used to cover UND personnel salary ($154,770), UND Travel ($8,862), UND equipment ($43,247), UND miscellaneous supplies ($3,800), UND analytical costs ($4,900) and UND indirect costs (F&A of $70,656).

UND - IES Personnel Salary Including Fringe Benefits

Salary estimates are based on the scope of work, and the labor rate used for specific personnel is based on their current salary rate. Generic labor categories have also been established with average labor rates. The table below gives the personnel cost breakdown. Any reference to hours worked on this grant is for budgeting purposes only. The University tracks employees' time based on effort percentage and will not track or report employees time worked on this project in hours. Final numbers may not agree due to rounding.

Personnel	Hours	Cost
Nasah, Project Manager	64	$ 3,942.00
Nicholas Dyrstad-Cincotta, PI	1387	$ 68,607.00
Research Engineer	867	$ 36,754.00
Graduate Researcher	1560	$ 43,491.00
Resource Manager	64	$ 1,975.00
Total	3942	$ 153,661.00

Hours for Project

Personnel	Role	Labor Rate Basis	Proposed Hours	Hourly Rate	Labor Cost	
Mann	Director	annual salary	0	96.91	$ -	
	Faculty	annual salary	0	65.00	$ -	
Nasah	Project Manager	annual salary	64	43.99	$ 2,816	
Dyrstad-Cincotta	PI	annual salary	1387	35.34	$49,005	
	Research Engineer	annual salary	867	35.34	$30,628	
Olson	Program Resource M	annual salary	64	22.04	$ 1,411	
Graduate	Graduate	annual salary	1560	27.74	$43,275	
				Total		$ 127,135

Salary In Months

Labor Type	Budget Period 1							
	Base Salary	Duration (Months)			Requested Salary ($)	Rate	Fringe Benefits	Grand Total
		Cal. Months	Acad. Months	Sum. Months				
Mann	201,573	0.00	0.00	0.00	0	0.40	0	0
0	135,200	0.00	0.00	0.00	0	0.40	0	0
Nasah	91,499	0.37	0.37	0.00	2816	0.40	1126	3942
Dyrstad-Cincotta	73,507	8.00	5.50	2.50	49005	0.40	19602	68607
0	73,507	5.00	3.00	2.00	30628	0.20	6126	36754
Olson	45,843	0.37	0.37	0.00	1411	0.40	564	1975
Graduate	57,699	9.00	6.00	3.00	43275	0.01	216	43491
Total:					127135		27635	$154,770

Fringe Benefits

Fringe benefits are estimated for proposal purposes only. On award implementation, only the true cost of each individual's fringe benefit plan will be charged to the project. Fringe benefits are estimated based upon the current rates for each labor category.

Travel

A breakdown of travel is presented in the table below and includes travel sampling field trips, equipment set-up and teardown. Costs have been estimated based on available airfare and lodging rates, conference fees, standard per diems and other UND travel policies. The sampling trips will include travel to wind turbines in the state. Estimates are broken down as follows:

Equipment Item	# of Days	# of travelers	Lodging	Flight	Mileage	Per Diem	Total Cost	Depart From	Destination
Wind Turbine 1 Start Q1	2	2	86	0	$322	$35	$1,774	GFK	
Wind Turbine 1 Q2	1	1	86	0	$322	$35	$443	GFK	
Wind Turbine 1 Q3	1	1	86	0	$322	$35	$443	GFK	
Wind Turbine 1 Final Q4	2	2	86	0	$322	$35	$1,772	GFK	
Wind Turbine 2 Start Q1	2	2	86	0	$322	$35	$1,772	GFK	
Wind Turbine 2 Q2	1	1	86	0	$322	$35	$443	GFK	
Wind Turbine 2 Q2	1	1	86	0	$322	$35	$443	GFK	
Wind Turbine 2 Final Q4	2	2	86	0	$322	$35	$1,772	GFK	
			0	0	$322	$35	$0		
			0	0	$322	$35	$0		
			0	0	$322	$35	$0		
PROJECT TOTAL							$8,862		

Equipment

Equipment cost has been estimated based upon our previous experience working on the ELF technology. We have recent vendor quotations for generically similar equipment. Formal quotes will be obtained during the project once the final design specifications have been determined.

c. Equipment

Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Elf Research Units	2.00	$15,038	$30,076	Based on prior market rates for existing units	Required for in-house parametric testing
Elf Prototype	1.00	$8,420	$8,240	Based on prior scaled-down experience	Required for developing miniaturized ELF unit
Data aquisiton and National Instruments Hardware	1.00	$4,931	$4,931	Online Quote/Prior Experience	Required for data measurements and controls
PROJECT TOTAL			$43,247		

As a result of this project, two ELF research units and one scaled-down ELF prototype will be built, along with independent data acquisition and control hardware to test the equipment. At the end of the project, ownership of the ELF research units and prototype will be transferred to ELF Technology, LLC.

Supplies

The bulk of the supplies will be associated with fabrication of the test systems and their operation. Therefore, the supplies budget is an estimate based upon experience in building and operating similar scale equipment.

Fees – Equipment Use and Laboratory Services / Other

This budget line includes several different categories of fees. The project scope of work includes characterization of selected feedstocks. A series of laboratory and analytical tests are required to complete the project. The following table gives a breakdown of these costs, with the basis of costs being established equipment use rates at UND, as well as advertised rates a various laboratory service providers.

Detailed Budget Justification					University of North Dakota
			e. Supplies		
Materials & Supplies	Quantity	Unit Cost	Total Cost	Basis of Cost	Justification of need
Shop Materials	1	$1,000	$1,000	Estimate	Misc. (Nuts, bolts, screws etc)
Laboratory supplies	1	$500	$500	"	Safety gloves, masks, eye wear etc
Additives	1	$2,300	$2,300	"	For particulate removal efficiency testing
	0	$0	$0		
Total			$3,800		
Publication costs	Quantity	Unit Cost	Total Cost	Basis of Cost	Justification of need
printing supplies		$100	$0	Estimate	reporting
paper		$25	$0	"	reporting
office supplies		$500	$0	"	misc. (pens, paper, clips, mailing, suppies, binders, folders)
Total			$0		
Professional Fees	Quantity	Unit Cost	Total Cost	Basis of Cost	Justification of need
XRD	50	$49	$2,450	Estimate	reporting
SEM	50	$49	$2,450	"	reporting
			$0	"	misc. (pens, paper, clips, mailing, suppies, binders, folders)
Total			$4,900		
Grand Total			8,700.00		

Subcontracts

UND anticipates no subcontracts in this project.

Indirect Costs

The indirect cost rate included in this proposal is the federally approved rate for UND of 41%. The indirect cost method is the Modified Total Direct Cost method, defined as the total direct cost of the project minus equipment in excess of $5000, the first $25,000 of each subcontract in excess of this value, tuition remission, and in-kind cost share contributions. Attached below is the negotiated indirects schedule for the University of North Dakota. Note, only sections highlighted in yellow are applicable to this grant request.

External Cost Share

ELF will contribute $198,380 of in-kind cost share towards the project's completion and NextEra will contribute $100,000 of in kind cost share, bringing private industry investment to 51% of the projects total cost.

ELF Technology, LLC.

ELF Technologies will provide $198,380 of in-kind cost share. Cost share includes personnel, travel, equipment, supplies, subcontracts, and indirect costs. Attached below is a breakdown of the indirect costs.

NextEra Energy, Inc.

NextEra will provide $100,000.00 of in-kind expenses, including: i) offering their facility to host a field demonstration, ii) Assistance with oil sampling and analysis, and iii) engineering support given through technology review in teleconference and in-person meetings. They also agree to send samples for analysis according the sampling protocol established by UND for the length of the field demonstration.

COLLEGES AND UNIVERSITIES RATE AGREEMENT

EIN: 45-6002491

ORGANIZATION:
University of North Dakota
Budget
264 Centennial Drive
Stop 8233
Grand Forks, ND 58202-8233

DATE:10/22/2019

FILING REF.: The preceding agreement was dated 07/25/2019

The rates approved in this agreement are for use on grants, contracts and other agreements with the Federal Government, subject to the conditions in Section III.

SECTION I: INDIRECT COST RATES

RATE TYPES: FIXED FINAL PROV. (PROVISIONAL) PRED. (PREDETERMINED)

	EFFECTIVE PERIOD				
TYPE	**FROM**	**TO**	**RATE(%)**	**LOCATION**	**APPLICABLE TO**
PRED.	07/01/2018	06/30/2019	39.00	On-Campus	(A) Org. Res.
PRED.	07/01/2019	06/30/2023	41.00	On-Campus	(A) Org. Res.
PRED.	07/01/2018	06/30/2023	26.00	Off-Campus	(A) Org. Res.
PRED.	07/01/2018	06/30/2019	50.50	On-Campus	(A) EERC (1)
PRED.	07/01/2019	06/30/2023	51.00	On-Campus	(A) EERC (1)
PRED.	07/01/2018	06/30/2023	26.00	Off-Campus	(A) EERC (1)
PRED.	07/01/2018	06/30/2020	35.60	On-Campus	(C) Oth Spo Pro
PRED.	07/01/2020	06/30/2023	35.00	On-Campus	(C) Oth Spo Pro
PRED.	07/01/2018	06/30/2023	26.00	Off-Campus	(C) Oth Spo Pro
PRED.	07/01/2018	06/30/2019	17.00	On-Campus	(C) HNRC (2)
PRED.	07/01/2019	06/30/2023	18.00	On-Campus	(C) HNRC (2)
PRED.	07/01/2018	06/30/2019	43.90	On-Campus	(C) Instruction
PRED.	07/01/2019	06/30/2023	43.00	On-Campus	(C) Instruction
PRED.	07/01/2018	06/30/2023	26.00	Off-Campus	(C) Instruction
PRED.	07/01/2018	06/30/2019	39.50	On-Campus	(B) Org. Res.
PRED.	07/01/2019	06/30/2023	42.00	On-Campus	(B) Org. Res.
PRED.	07/01/2018	06/30/2023	27.50	Off-Campus	(B) Org. Res.
PRED.	07/01/2018	06/30/2019	51.50	On-Campus	(B) EERC (1)

ORGANIZATION: University of North Dakota

AGREEMENT DATE: 10/22/2019

TYPE	FROM	TO	RATE(%)	LOCATION	APPLICABLE TO
PRED.	07/01/2019	06/30/2023	52.00	On-Campus	(B) EERC (1)
PRED.	07/01/2018	06/30/2023	27.50	Off-Campus	(B) EERC (1)
PROV.	07/01/2023	Until Amended		(D)	

*BASE

Modified total direct costs, consisting of all direct salaries and wages, applicable fringe benefits, materials and supplies, services, travel and up to the first $25,000 of each subaward (regardless of the period of performance of the subawards under the award). Modified total direct costs shall exclude equipment, capital expenditures, charges for patient care, rental costs, tuition remission, scholarships and fellowships, participant support costs and the portion of each subaward in excess of $25,000. Other items may only be excluded when necessary to avoid a serious inequity in the distribution of indirect costs, and with the approval of the cognizant agency for indirect costs.

(1) Energy and Environmental Research Center
(2) Human Nutrition Research Center

(A) Facilities and Administrative Cost Rates
(B) Facilities and Administrative Cost Rates - DOD Contracts Only
(C) (A) & (B) apply

(D) Use same rates and conditions as those cited for fiscal year ending June 30, 2023.

SECTION I: FRINGE BENEFIT RATES**

TYPE	FROM	TO	RATE(%)	LOCATION	APPLICABLE TO
FIXED	7/1/2019	6/30/2020	28.00	All (1)	EERC-Permanent Employees
PROV.	7/1/2020	6/30/2023	28.00	All (1)	EERC-Permanent Employees

** DESCRIPTION OF FRINGE BENEFITS RATE BASE:

Direct salaries and wages excluding other fringe benefits.

(1) Vacation, holiday, and sick leave rate

SECTION II: SPECIAL REMARKS

TREATMENT OF FRINGE BENEFITS:

This organization charges the actual cost of each fringe benefit direct to Federal projects. However, it uses a fringe benefit rate which is applied to salaries and wages in budgeting fringe benefit costs under project proposals. The fringe benefits listed below are treated as direct costs:
SOCIAL SECURITY, HEALTH/LIFE INSURANCE, WORKERS COMPENSATION, UNEMPLOYMENT INSURANCE, RETIREMENT (STATE, TFFR, OR TIAA/CREF), DISABILITY INSURANCE, AND EMPLOYEE ASSISTANCE PROGRAM

TREATMENT OF PAID ABSENCES

Except for EERC Employees, vacation, holiday, sick leave pay and other paid absence are inlcuded in salaries and wages and are charged to federal projects as part of the normal charge for salaries and wages. Separate charges for the cost of these absences are not made.

For EERC employees, the cost of vacation, holiday, sick leave pay, and other paid absences (and associated other fringe benefits) are included in a fringe benefit rate and are not included in direct charges for salaries and wages. Charges for salaries and wages must exclude those paid to EERC employees for periods when they are on vacation, holiday, or sick leave, or are otherwise absent from work.

DEFINITION OF OFF-CAMPUS
An off-campus activity is defined as that activity performed by University employees at locations other than the main campus and not using the University's operation and maintenance facilities.

Activity such as short term (less than one month's duration) travel by employees to an off-campus site where office space is maintained on campus in their absence shall be considered on campus activity for the purposes of applying the indirect cost rates. Travel in excess of one month's duration will be reviewed and classified on or off campus on a case by case basis.

Activity performed by other than University employees through contractual arrangements is normally considered on campus with only the first $25,000 subject to the on campus indirect cost rate.

DEFINITION OF EQUIPMENT

Equipment means tangible personal property (including information technology systems) having a useful life of more than one year and a per-unit acquisition cost which equals or exceeds $5,000.

NEXT PROPOSAL DUE DATE

An indirect cost proposal based on actual costs for fiscal year ending 06/30/22, will be due no later than 12/31/22.
A fringe benefit proposal based on actual costs for fiscal year ending 06/30/19, will be due no later than 12/31/19.

SECTION III: GENERAL

A. LIMITATIONS:

The rates in this Agreement are subject to any statutory or administrative limitations and apply to a given grant, contract or other agreement only to the extent that funds are available. Acceptance of the rates is subject to the following conditions: (1) Only costs incurred by the organization were included in its facilities and administrative cost pools as finally accepted: such costs are legal obligations of the organization and are allowable under the governing cost principles; (2) The same costs that have been treated as facilities and administrative costs are not claimed as direct costs; (3) Similar types of costs have been accorded consistent accounting treatment; and (4) The information provided by the organization which was used to establish the rates is not later found to be materially incomplete or inaccurate by the Federal Government. In such situations the rate(s) would be subject to renegotiation at the discretion of the Federal Government.

B. ACCOUNTING CHANGES:

This Agreement is based on the accounting system purported by the organization to be in effect during the Agreement period. Changes to the method of accounting for costs which affect the amount of reimbursement resulting from the use of this Agreement require prior approval of the authorized representative of the cognizant agency. Such changes include, but are not limited to, changes in the charging of a particular type of cost from facilities and administrative to direct. Failure to obtain approval may result in cost disallowances.

C. FIXED RATES:

If a fixed rate is in this Agreement, it is based on an estimate of the costs for the period covered by the rate. When the actual costs for this period are determined, an adjustment will be made to a rate of a future year(s) to compensate for the difference between the costs used to establish the fixed rate and actual costs.

D. USE BY OTHER FEDERAL AGENCIES:

The rates in this Agreement were approved in accordance with the authority in Title 2 of the Code of Federal Regulations, Part 200 (2 CFR 200), and should be applied to grants, contracts and other agreements covered by 2 CFR 200, subject to any limitations in A above. The organization may provide copies of the Agreement to other Federal Agencies to give them early notification of the Agreement.

E. OTHER:

If any Federal contract, grant or other agreement is reimbursing facilities and administrative costs by a means other than the approved rate(s) in this Agreement, the organization should (1) credit such costs to the affected programs, and (2) apply the approved rate(s) to the appropriate base to identify the proper amount of facilities and administrative costs allocable to these programs.

BY THE INSTITUTION:

University of North Dakota

(INSTITUTION)

(SIGNATURE)

Jed M. Shivers

(NAME) Vice President for Finance & Operations/COO
University of North Dakota

(TITLE)

30 October 2019

(DATE)

ON BEHALF OF THE FEDERAL GOVERNMENT:

DEPARTMENT OF HEALTH AND HUMAN SERVICES

(AGENCY)

Arif M. Karim -S Digitally signed by Arif M. Karim -S DN: c=US, o=U.S. Government, ou=HHS, ou=PSC, ou=People, cn=Arif M. Karim -S, 0.9.2342.19200300.100.1.1=2000212895 Date: 2019.10.26 17:10:48 -05'00'

(SIGNATURE)

Arif Karim

(NAME)

Director, Cost Allocation Services

(TITLE)

10/22/2019

(DATE) 7110

HHS REPRESENTATIVE: Karen Wong

Telephone: (415) 437-7820

UNIVERSITY OF NORTH DAKOTA
FACILITIES AND ADMINISTRATIVE COST RATES
FOR THE PERIOD JULY 1, 2018 THROUGH JUNE 30, 2023

	ORGANIZED RESEARCH					
	JULY 1, 2018 - JUNE 30, 2019			JULY 1, 2019 - JUNE 30, 2023		
		ON-CAMPUS	OFF-CAMPUS		ON-CAMPUS	OFF-CAMPUS
BUILDING DEPRECIATION		1.30%			2.50%	
BUILDING INTEREST		0.00%			0.10%	
EQUIPMENT DEPRECIATION		2.70%			2.00%	
OPERATIONS & MAINTENANCE		7.80%			9.20%	
LIBRARY		1.20%			1.20%	
GENERAL ADMIN	7.20%			6.10%		
DEPT ADMIN	14.60%			15.70%		
SPON PROJ ADMIN	4.20%			4.20%		
STUDENT SERV ADMIN	0.00%			0.00%		
ADMIN COMPONENTS	26.00%	26.00%	26.00%	26.00%	26.00%	26.00%
TOTAL		39.00%	26.00%		41.00%	26.00%

	ENERGY & ENVIRONMENTAL RES CTR (EERC)					
	JULY 1, 2018 - JUNE 30, 2019			JULY 1, 2019 - JUNE 30, 2023		
		ON-CAMPUS	OFF-CAMPUS		ON-CAMPUS	OFF-CAMPUS
BUILDING DEPRECIATION		1.40%			1.40%	
BUILDING INTEREST		1.20%			0.70%	
EQUIPMENT DEPRECIATION		1.20%			2.00%	
OPERATIONS & MAINTENANCE		18.80%			19.20%	
LIBRARY		1.90%			1.70%	
GENERAL ADMIN	6.00%			6.00%		
DEPT ADMIN	16.50%			16.70%		
SPON PROJ ADMIN	3.50%			3.30%		
STUDENT SERV ADMIN	0.00%			0.00%		
ADMIN COMPONENTS	26.00%	26.00%	26.00%	26.00%	26.00%	26.00%
TOTAL		50.50%	26.00%		51.00%	26.00%

REFLECTS PROVISIONS OF APPENDIX III TO PART 200 OF UNIFORM GUIDANCE - INDIRECT (F&A) COSTS IDENTIFICATION AND ASSIGNMENT, AND RATE DETERMINATION FOR INSTITUTIONS OF HIGHER EDUCATION (IHEs), C.8 DATED SEPTEMBER 10, 2015.

CONCUR:

(SIGNATURE) Jed M. Shivers

TITLE Vice President for Finance & Operations University of N.

DATE 30 October 2019

UNIVERSITY OF NORTH DAKOTA
FACILITIES AND ADMINISTRATIVE COST RATES
FOR THE PERIOD JULY 1, 2018 THROUGH JUNE 30, 2023

DOD CONTRACTS ONLY

	ORGANIZED RESEARCH					
	JULY 1, 2018 - JUNE 30, 2019			JULY 1, 2019 - JUNE 30, 2023		
		ON-CAMPUS	OFF-CAMPUS		ON-CAMPUS	OFF-CAMPUS
BUILDING DEPRECIATION		1.00%			2.00%	
BUILDING INTEREST		0.00%			0.10%	
EQUIPMENT DEPRECIATION		2.00%			2.00%	
OPERATIONS & MAINTENANCE		7.80%			9.20%	
LIBRARY		1.20%			1.20%	
GENERAL ADMIN	7.70%			6.10%		
DEPT ADMIN	15.10%			16.90%		
SPON PROJ ADMIN	4.70%			4.50%		
STUDENT SERV ADMIN	0.00%			0.00%		
ADMIN COMPONENTS	27.50%	27.50%	27.50%	27.50%	27.50%	27.50%
TOTAL		39.50%	27.50%		42.00%	27.50%

	ENERGY & ENVIRONMENTAL RES CTR (EERC)					
	JULY 1, 2018 - JUNE 30, 2019			JULY 1, 2019 - JUNE 30, 2023		
		ON-CAMPUS	OFF-CAMPUS		ON-CAMPUS	OFF-CAMPUS
BUILDING DEPRECIATION		1.40%			1.40%	
BUILDING INTEREST		1.20%			0.70%	
EQUIPMENT DEPRECIATION		1.20%			2.00%	
OPERATIONS & MAINTENANCE		18.10%			18.70%	
LIBRARY		2.10%			1.70%	
GENERAL ADMIN	6.30%			6.10%		
DEPT ADMIN	17.60%			16.90%		
SPON PROJ ADMIN	3.60%			4.50%		
STUDENT SERV ADMIN	0.00%			0.00%		
ADMIN COMPONENTS	27.50%	27.50%	27.50%	27.50%	27.50%	27.50%
TOTAL		51.50%	27.50%		52.00%	27.50%

REFLECTS PROVISIONS OF APPENDIX III TO PART 200 OF UNIFORM GUIDANCE - INDIRECT (F&A) COSTS IDENTIFICATION AND ASSIGNMENT, AND RATE DETERMINATION FOR INSTITUTIONS OF HIGHER EDUCATION (IHEs), C.8 DATED SEPTEMBER 10, 2015.

CONCUR:

Jed M. Shivers
(SIGNATURE)

Vice President for Finance & Operations/COO
University of North Dakota
TITLE

20 October 2019
DATE

UNIVERSITY OF NORTH DAKOTA
FACILITIES AND ADMINISTRATIVE COST RATES
FOR THE PERIOD JULY 1, 2018 THROUGH JUNE 30, 2023

	OTHER SPONSORED ACTIVITIES						INSTRUCTION		
	JULY 1, 2018 - JUNE 30, 2020			JULY 1, 2020- JUNE 30, 2023			JULY 1, 2018 - JUNE 30, 2019		
		ON-CAMPUS	OFF-CAMPUS		ON-CAMPUS	OFF-CAMPUS		ON-CAMPUS	OFF-CAMPUS
BUILDING DEPRECIATION		0.60%			1.20%			1.70%	
BUILDING INTEREST		0.00%			0.00%			0.00%	
EQUIPMENT DEPRECIATION		3.70%			1.90%			1.70%	
OPERATIONS & MAINTENANCE		3.80%			4.40%			7.30%	
LIBRARY		1.50%			1.50%			7.20%	
GENERAL ADMIN	7.00%			6.00%			6.00%		
DEPT ADMIN	14.70%			15.70%			12.80%		
SPON PROJ ADMIN	4.30%			4.30%			0.20%		
STUDENT SERV ADMIN	0.00%			0.00%			7.00%		
ADMIN COMPONENTS	26.00%	26.00%	26.00%	26.00%	26.00%	26.00%	26.00%	26.00%	26.00%
TOTAL		35.60%	26.00%		35.00%	26.00%		43.90%	26.00%

	HUMAN NUTRITION RESEARCH CENTER				INSTRUCTION		
	JULY 1, 2018 - JUNE 30, 2019		JULY 1, 2019 - JUNE 30, 2023		JULY 1, 2019 - JUNE 30, 2023		
		ON-CAMPUS		ON-CAMPUS		ON-CAMPUS	OFF-CAMPUS
BUILDING DEPRECIATION		0.10%		0.10%		2.00%	
BUILDING INTEREST		0.00%		0.00%		0.00%	
EQUIPMENT DEPRECIATION		0.00%		0.00%		1.30%	
OPERATIONS & MAINTENANCE		0.00%		0.00%		7.10%	
LIBRARY		1.00%		1.00%		6.60%	
GENERAL ADMIN	7.20%		6.00%		6.00%		
DEPT ADMIN	4.00%		6.30%		12.80%		
SPON PROJ ADMIN	4.70%		4.60%		0.20%		
STUDENT SERV ADMIN	0.00%		0.00%		7.00%		
ADMIN COMPONENTS	15.90%	15.90%	16.90%	16.90%	26.00%	26.00%	26.00%
TOTAL		17.00%		18.00%		43.00%	26.00%

REFLECTS PROVISIONS OF APPENDIX III TO PART 200 OF UNIFORM GUIDANCE - INDIRECT (F&A) COSTS IDENTIFICATION AND ASSIGNMENT, AND RATE DETERMINATION FOR INSTITUTIONS OF HIGHER EDUCATION (IHEs), C.8 DATED SEPTEMBER 10, 2015.

CONCUR:

(SIGNATURE) **Jed M. Shivers**

Vice President for Finance & Operations/COO
University of [illegible]

TITLE

20 October 2019

DATE

Nicholas Dyrstad-Cincotta (M.Sc.)
Engineer, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153
Email: Nicholas.dyrstadcinc@und.edu
Phone: 612-385-1288

Re: The Renewable Energy Council Grant proposal

Nic,

Regarding the request for greater clarification of the Indirect Costs line item on the above referenced proposal, please accept the following further breakdown of this aggregate number.

Office rental, 4200 James Ray Drive, GF, ND.	$ 1,000.00
Office space, 501 Main Street N., Stillwater, Mn.	$ 5,000.00
Office overhead	$ 3,500.00
Office administration labor	$ 8,250.00
Insurances	$ 5,000.00
Benefits 7%	$ 1,000.00
Legal (patent)	$ 5,000.00
Legal (Corporate)	$ 2,500.00

I trust this will accomplish what the request was for. If there are any additional question or further clarification, please do not hesitate to let me know. Thanks to you and the team for all of the effort and work applicable to this process.

Sincerely

James K. Rickson

President & CEO
ELF Technology, LLC.