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July 28, 2022

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

Subject: "Production of Renewable Hydrogen and Valuable Carbons," Proposal to the Renewable Energy Program by Dr. Johannes van der Watt, Principal Investigator

Dear Ms. Fine:

On behalf of the University of North Dakota, I am pleased to submit Dr. Johannes van der Watt's proposal on "Production of Hydrogen and Valuable Carbons from Methane-Sources" for consideration by the NDIC's Renewable Energy Program. Dr. Van der Watt is a Research Engineer in UND's Institute for Energy Studies and is the Principal Investigator for this project. Dr. Van der Watt is proposing a one-year project with a total requested amount from NDIC of $180,000. Dr. Van der Watt's industry partner, Envergex, together with UND, have agreed to provide matching contributions valued at $180,000 ($100,000 match from Envergex, plus $80,000 match from UND), for a total project value of $360,000.

Please contact Dr. Van der Watt with any technical questions about the project at (701) 777-5177 or johannes.vanderwatt@und.edu.

The $100 application fee is currently being processed as an electronic payment by UND and should reach your office in a timely manner.

Thank you for your consideration of this proposal.

Sincerely yours,

Karen Katrinak

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

Renewable Energy Program

North Dakota Industrial Commission

Application

Project Title: Production of Hydrogen and Valuable Carbons from Methane-Sources

Applicant: University of North Dakota

Principal Investigator: Johannes van der Watt

Date of Application: August 1, 2022

Amount of Request: $180,000

Total Amount of Proposed Project: $360,000

Duration of Project: 1 year

Point of Contact (POC): Johannes van der Watt

POC Telephone: 701-777-5177

POC Email: Johannes.vanderwatt@und.edu

POC Address: University of North Dakota CEC Rm. 246D, 2844 Campus Rd. Stop 8153, Grand Forks, ND 58202

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ABSTRACT

Objective: The University of North Dakota – Institute for Energy Studies (UND-IES) and project partner Envergex LLC are proposing to reduce the cost of renewable hydrogen (H_2) to <$2.00 per kilogram (kg) by decomposing biomethane via a catalytic decomposition process. The catalytic decomposition of methane (CDM) reaction is endothermic, requiring about 38 kJ/mol-H_2 to break up CH_4, several-fold less energy than water electrolysis (~280 kJ/mol-H_2). *Whereas steam methane reforming generates CO_2 gas, requiring pressurization and geologically sequestering, CDM generates solid carbon eliminating the need for costly and complex CO_2 capture and sequestering.* The key to this technology is integrating electrical and combustion heating to overcome the challenges associated with the intermittency of renewable power sources like wind or solar. If in the form of carbon nanotubes (CNT), CDM-derived C also has potential uses in lithium-ion batteries (LIBs). The synthesis parameters influence the carbon's type, quality, and value. Depending on the type, CNT costs can range from $500/kg to $2-million/kg.[1, 2] We intend to characterize the C and test its performance in electrochemistry devices to determine its potential value within this niche application.

Expected Results: We expect to provide H_2 producers the opportunity to seamlessly integrate intermittent renewable power technologies into their manufacturing systems *and decrease the cost of renewable or green H_2 compared to other green H_2 production technologies*. Green H_2 is currently much more expensive than gray ($2.50/kg - $4.50/kg for green vs. $1.25/kg - $2.00/kg for gray) [3]. Gray H_2 is derived from fossil fuels. This project aims to decrease the cost difference between green and gray H2 by improving the energy utilization of the production process and providing valuable carbon nanotubes (CNTs) to battery manufacturers. For every 1.00 kg CH_4 converted, 0.75 kg of C and 0.25 kg of H_2 can form. Valuable C can help reduce the cost of H_2 even further and position North Dakota (ND), with vast biomass-based resources, as a leading renewable resources provider in the U.S.A. This approach can achieve net-negative carbon emissions using renewable biomethane since C forms instead of carbon dioxide (CO_2). We expect *negative C emissions of approximately minus (-) 2 kg CO_2 equivalent per kg H_2 for this technology approach.*

Duration: 12 months (Suggested: December 2022 – December 2023).

Total Project Cost: $180,000 (50%) requested from NDIC of the $360,000 total project cost. The U.S. Department of Energy is providing the balance.

Participants: University of North Dakota – Institute for Energy Studies and Envergex LLC.

PROJECT DESCRIPTION

Objectives: This project aims to develop a low-cost, H_2 production strategy that maximizes the use of renewable resources and value-added carbon byproducts. The design allows H_2 manufacturers to use a combination of low-cost heating methods to produce H_2. Low-cost electricity provides an exceptionally favorable H_2 manufacturing advantage when using the CDM method. The energy input for this process is ~15 MWh/tonne H_2, meaning the operating cost can reach lows of about $0.15/kg (assuming low electricity pricing of ~ $10/MWh). Conversely, when electricity prices are high (~$100/MWh), operating costs would be high (~ $1.50/kg H_2) if electrical heat is used as input; alternative lower-cost heat input sources should be used during this time. Electrolyzers ($H_2O \rightarrow H_2 + \frac{1}{2}O_2$) consume much higher energy than methane decomposition, of about 50-60 MWh/tonne of H_2, with costs of about $0.5/kg – $5.00/kg at equivalent electricity costs. The variability of renewable energy resources makes efficient, low-cost H_2 production more difficult.

Nevertheless, H_2 can be produced and stored during low electricity pricing conditions and, when required, consumed to produce more H_2 since the reaction between H_2 and O_2 can release enough energy to decompose additional CH_4 and sustain H_2 production rates. We intend to identify the best combination for using electricity heating vs. combustion heating for CDM.

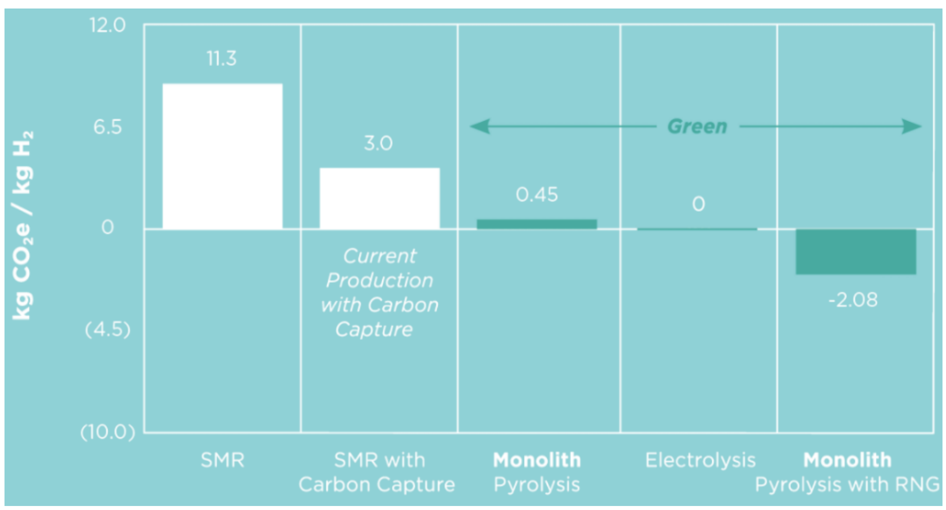

Figure 1: Carbon intensity of H_2 production (taken from Monolith, 2022 [4])

Valuable Carbon Potential: In addition to establishing a cost-competitive process, the other important objective is to reduce carbon emissions associated with H_2 production. Figure 1 [4] shows the carbon intensity of steam methane reforming (SMR) with and without carbon capture, pyrolysis with natural gas and renewable natural gas (RNG), and electrolysis. Using renewable resources can drastically reduce carbon intensity compared to leading SMR techniques. Solid carbon can also be a viable product.

Various nano-carbons can form during the CDM process, as shown in Figure 2 [5]. CNTs are especially valuable within the battery industry and can be used (in quantities of about 0.5-1.0 wt.%) in LIBs to improve their performance compared to graphene.

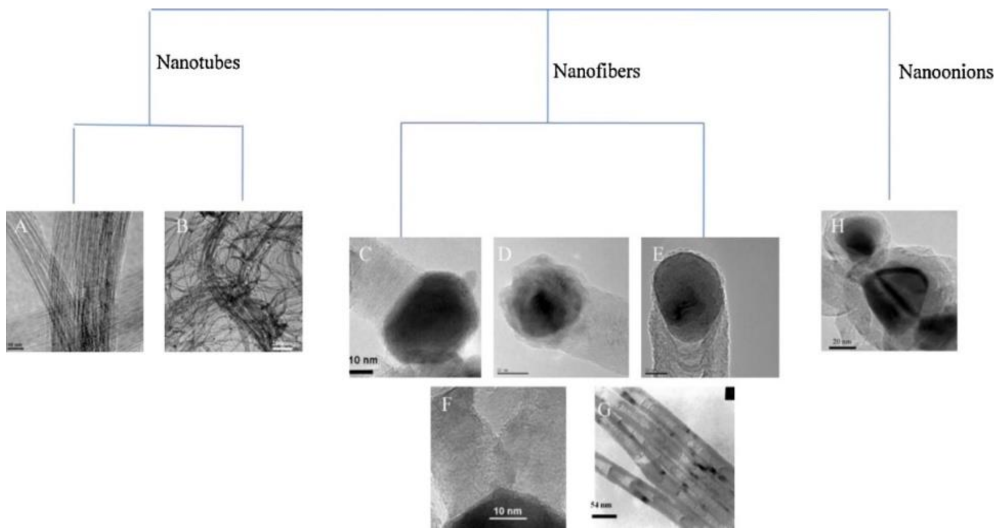

Figure 2: Nano-carbons from the CDM process (taken from Li et al., 2011 [5]).

CNTs' open structure and enriched chirality improve the capacity and electrical transport of CNT-based LIBs, thereby improving their performance. CNTs can be produced via the CDM process. Still, from a review article by Välimäki *et al.* (2021) [6] it is evident that the quality/concentration of CNTs to other carbon forms are not always reported. *The qualitative characterization of these CNTs is important, but actual battery performance tests are required to assess their value to attain a quantitative result.* ***Clean Republic LLC***, a North Dakotan-based company marketing clean energy-relevant products such as LIB packs and solar water heating panels, has also indicated potential interest in the CNTs that can be produced from biomethane (See attached Letter of Interest from Clean Republic in Appendix D: Letter of Interest).

Methodology: Our technical approach seeks to develop targeted improvements to the CDM process. UND and Envergex are currently developing a technology for a federally funded project (DE-FE0032061) to make targeted improvements to the CDM process. The technology uses an electromagnetic energy-assisted mechanism, reducing downtime associated with catalyst reactivation or replacement due to poisoning. The conventional cleaning methods use air to combust the C, thereby forming CO_2 that needs separation from H_2. We intend to circumvent the combustion step to achieve a net-negative carbon process for valuable chemical manufacturing. ***The detailed technical description of the proposed technology is confidential and attached as Appendix F.***

Renewable power systems produce electricity from one or more renewable resources and often incorporate power from fossil fuels or energy storage devices for backup. Even though recent improvements in the economics of renewable power sources have made them competitive with conventional power sources in many situations, their novelty, intermittency, and geographic diversity mean numerous configurations can be employed. Our approach intends to use a fraction of the produced H_2 to power the CDM process using both electric heating and conventional combustion heating. However, the size and switching mechanisms between these energy resources need to be determined. Since renewable power system designers often use computer-based algorithms to predict performance and explore different design options, this extension to use H_2 as a backup resource fits perfectly into the modeling scheme.

Computer models, defined as simplified mathematical representations of real systems, can help overcome the challenges of integrating renewable resources for a constant power supply. Models allow the designer to simulate the long-term performance and economics of renewable power systems, explore different design options, and test the effects of input assumptions. Envergex examined the use of combined electrical and H_2 heating for a pyrolysis process and simulated the integration using Aspen Plus and a process/grid dispatch modeling tool. The output of this simulation is shown in Figure 3 and shows the H_2 storage level in response to the grid pricing.

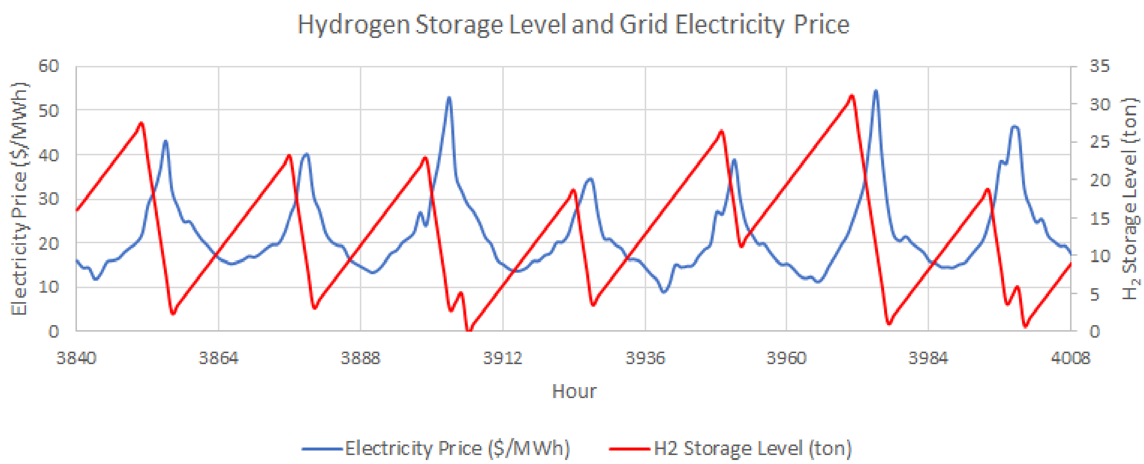

Figure 3: H_2 production using combination of electric and hydrogen heating.

As grid prices start to increase, H_2 is withdrawn from storage and burnt in the pyrolysis reactor; as grid prices fall, some of the produced H_2 is sent to storage, while the bulk is transferred as a product. This example illustrates the advantages of using combined heating processes to overcome the intermittency of renewable power resources while maintaining low production costs. However, the produced C can also be used as a valuable product in LIBs, and additional research is required to classify the composition and quality of these carbons. To develop these models and assess the value of the products, the team will conduct three additional tasks to complement the current Department of Energy Project. The three additional tasks form part of the scope extension and follow the original five tasks of DE-FE0032061:

Task 6 – Project Management and Planning: Applicant will manage and direct the project in accordance with a Project Management Plan to meet all technical, schedule and budget objectives and requirements as part of DE-FE0032061. Applicant will update the companion project's Project Management Plan and incorporate the scope extension proposed in this application. In addition, the purpose of this task is coordination and planning of the project. UND will lead this task with support from Envergex to address all items related to monitoring and control of project scope, cost, and schedule. Applicant will compile quarterly technical reports, topical reports, participate in meetings and make presentations at conferences as required.

Task 7 – Evaluation and Characterization of Carbon Products: Applicant will use a laboratory-scale thermocatalytic CH_4 conversion system to produce and collect carbon as part of the DE-FE0032061 project. The carbons that are formed during this process could have the potential for use in LIB electrodes. The Applicant will collect and characterize these carbons to see if they exhibit the characteristics of high-quality CNTs. The focus of this task is to understand how the operating conditions of the cleaning system affect the size and purity of the removed carbon species and whether the conditions that maximize H_2 production also correspond with high-quality CNT synthesis. UND will lead this task, relying on the experience of consultant Dr. Yong Hou (see resume in Appendix B) in battery manufacturing and testing.

The removal method of the carbons is confidential and included (Appendix F – Confidential Information) for review purposes. This task will also focus on characterizing the carbon materials for structure, composition, and purity; this will be completed using Scanning Electron Microscope with Energy Dispersive X-ray Spectroscopy (SEM-EDS) and

Transmission Electron Microscopy (TEM). The SEM and TEM images will help determine the carbons' size and structure. Additional carbons will be synthesized using a thermogravimetric analyzer (TGA) and UND's laboratory-scale CH_4 decomposition system. The goal is to use the same materials as those for the CH_4 decomposition tasks in project DE-FE0032061, but here the focus will be on characterizing the synthesized carbons. Materials proposed for this task include bimetallic transition metals (for example, iron, nickel, and activated carbon) supported on materials substrates, including alumina, silica, titania, and magnesia. If the carbons display good properties in terms of purity and structure, the best quantification method is assembling a battery and testing its output performance.

The performance of the CNT containing battery materials will be tested using a CR2032 coin-type cell (for lab-scale sample). Current densities and specific capacities will be calculated based on the mass of the target compound of the electrode. Cycle life will be evaluated by using a three-electrode system (ECC-REF, EL-Cell GmbH, Germany) for cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) tests available at IES.

Task 8 – Process Model of Greener H_2 Production System: Applicant will develop a software toolkit that uses variable grid prices for electricity as input, along with detailed capital and operating costs for storage and utilization options. In addition, we will evaluate the net present value of investments into the proposed H_2 manufacturing process across different future scenarios of the hybrid heating configuration (electric and combustion). Using both electric and combustion heating for methane decomposition would provide greater flexibility depending on the availability of the energy resources.

Envergex will lead this task to develop integration methods, relying on techniques created for energy storage applications within the utility sector (DE-SC0020863) using open-sourced process simulator platforms and Aspen Plus. This information can then be used in an iterative fashion to optimize the design. By combining Aspen Plus with uncertainty quantification tools such as Raven [7], more detailed parametric studies can be conducted to design an optimum process for specific conditions. UND will support Envergex in setting up the Aspen simulations.

Anticipated Results: 1) A computer model that benefits H_2 manufacturers by preserving the reliability of operations when having to rely on the variable nature of renewable energy resources; 2) Competitive H_2

production costs (<$2.00/kg) compared to renewable electrolysis- or plasma-based processes because of the novel heat integration strategy; 3) Valuable products manufacturing setup with potential for net-negative carbon emissions of approximately negative (-) 2.0 kilograms CO_2 equivalent per kg H_2 when used in combination with biomethane; 4) CNTs suitable for use in the electrodes of LIBs.

Facilities: UND has exceptional analytical, laboratory, and fabrication facilities, including a mechanical/electrical fabrication shop. UND Advanced Materials Characterization Laboratory (AMCL) analytical capabilities will be leveraged to characterize the physical/chemical properties of the carbons evaluated. In addition, UND has High-Performance Computing infrastructure in the Computational Research Center, available to all faculty members.

Resources: UND has fully equipped laboratories for material preparation and battery testing. UND's office areas are equipped with all of the necessary software and computing requirements to complete the scope of work. Some of the most relevant resources for this project include: 1) thermogravimetric Analyzer (TGA) & Differential Scanning Calorimeter (DSC) for CNT synthesis; 2) Lab-Scale Thermocatalytic CH_4 Conversion Test System for CNT removal; 3) Hitachi SEM 3400N with an Energy Dispersive System (SEM/EDS) for CNT characterization; 4) Carbon Analyzer TOC SSM 5000A analyzer (Shimadzu, Japan) for carbon content quantification; 5) Neware BTS-3000n Battery Analyzer for LIB with CNT performance testing; and 6) MBraun LABstar MB10 Glove Box for LIB assembly.

Techniques to Be Used, Their Availability and Capability: UND and Envergex will use experimental and computational techniques to respectively characterize the carbons that form during the CDM process and determine how to best integrate renewable power options for heat provision during the CDM process.

UND can assemble both CR2032 coin-type cells (for lab-scale sample) and full-size 18650 cells (for industrial approval testing). UND owns a license for Aspen Plus and the project team will use open source codes for optimization studies.

Environmental and Economic Impacts while Project is Underway: No environmental or economic impacts are anticipated during project execution.

Ultimate Technological and Economic Impacts: 1) Applicant's technology will allow for the development of a low-cost CO_2-free process for converting biomethane to H_2; 2) methane, a potent greenhouse gas, can be safely used without the concern of capturing and storing CO_2; 3) The solid C from this process is one of the best forms of carbon sequestration; 4) Improvements to the conventional thermo-catalytic hydrocarbon conversion process, to enable broader adoption of H_2 related technologies; 5) Less expensive CNTs could lead to greater use and improved battery performance; 6) Develop a modeling platform toolkit that can evaluate applications for the production of H_2 from biomethane – the tool will help integrate technology with energy producers.

Why the Project is Needed: *<u>Advancing H_2 production capabilities</u>* – H_2 is an energy vector, with projected demand for additional applications growing as costs of production drop. With the serviceable consumption potential for H_2 estimated to be 106 million metric tons per year (MMT/y) across nine applications, which is approximately 11 times larger than the 2015 U.S. on-purpose H_2 production of 10 MMT/y, the cost will be a major factor in ensuring increased adoption of H_2. According to H2@scale, a H_2 price of $1.50/kg is required to create demand three times (30 MMT/y) the current market size. With a significant potential H_2 market in power-intensive industrial processes such as metal refining (e.g., blast furnace/coke ovens replaced with direct reduction of iron (DRI) process using H_2), synthetic hydrocarbon production, ammonia, and biofuels production, there is a potential for H_2 demand to increase significantly in the short-term if climate change regulations become stringent.

<u>Existing versus proposed project</u> - Our goals for the existing project are to identify catalyst supports that enhance the proposed electromagnetic energy-assisted mechanism to ensure catalyst activity and maintain near initial condition activity without producing CO_2. The focus of the proposed project is to extend the applicability of this technology into the renewable market to ensure greener H_2 with a lower carbon footprint can be generated compared to the typical SMR processes.

The intent is to develop the software tools to help design the scale of equipment required and the switching algorithms to ensure the cheapest H_2 is always produced. Furthermore, the existing project is dedicated to the carbon removal technique, and the characterization of the carbons as battery components does not form part of this project. The focus of the proposed project is to characterize the carbon materials and see if this byproduct can be valorized.

STANDARDS OF SUCCESS

The following measurable deliverables will evaluate the success of this project:

1) Ability to identify and categorize the carbons that form upon decomposing CH_4 to determine an ancillary use for them as opposed to landfilling within ND
2) LIB performance comparable or better than LIBs using either commercial CNTs or none at all
3) Software tools that can be applied to different H_2 generating technologies to ensure the advantageous utilization of low priced electricity in ND;

BACKGROUND/QUALIFICIATIONS

The proposed technical team has a long history of conducting large, interdisciplinary, and multi-organizational research projects. For example, both organizations are key technical subcontractors on a $5 million dollar Department of Energy funded project to develop an aerosol mitigation technology for high alkali coals (DE-FE00031756). *Dr. Johannes van der Watt, Principal Investigator – UND-IES,* brings over five years of experience in modeling laboratory and pilot-scale systems. His background includes materials characterization, traditional and advanced energy generation, renewables, emissions control, and energy storage. *Dr. Daniel Laudal, Executive Director – UND-IES,* will ensure all required resources at the university can be leveraged where needed for project success. Dr. Laudal led the environmental regulatory compliance and environmental planning efforts for a generation & transmission cooperative serving eastern North Dakota and northwestern Minnesota. As Project Tundra Project Manager, he led Minnkota's development of a world-scale carbon capture and storage project for the Milton R. Yong Station, a lignite coal-fired power plant in ND. *Dr. Srivats Srinivasachar, Co-PI, President of Envergex LLC,* will be a technical advisor for the project. Dr. Srinivasachar has had a long career in the power industry (13 years at ABB Combustion Engineering, subsequently ALSTOM Power, Inc. and now GE, and 14 years at Envergex LLC). He brings expertise in facilitating the integration of energy storage systems with fossil-fueled generation using modeling tools. *Dr. Yong Hou, Materials Research*

<u>Engineer, President of Subzero Energy LLC</u>, will be a consultant and technical advisor in this project, guiding carbon characterization, processing, and use in battery applications. In addition, he will guide the team in testing and evaluating the performance of the batteries containing small amounts of CNTs. He has developed over ten variations of battery cell and battery pack products that have been applied successfully in the marketplace, including a bicycle battery being applied in Clean Republic's flagship product – Hilltopper. The team's resumes are included in Appendix B: Resumes.

MANAGEMENT

Dr. Van der Watt will serve as the project PI and the contact person for UND and will be responsible for the coordination of project activities. He will lead Tasks 6 and 7, and serve as technical advisor for Task 8. Dr. Laudal will oversee the research activities and assist in ensuring the project's successful completion. He will also work with the project team to ensure all personnel, equipment, and other resources are available to conduct the project efficiently. Dr. Srinivasachar will serve as a Co-PI and contact person for Envergex (see Appendix C: Letter of Commitment). He will be involved in all tasks as a technical advisor and will lead Task 8. Once awarded, the following items will be addressed throughout the project: 1) Monitor project scope, schedule, cost, and risk; 2) Update project plans periodically to reflect changes in scope, schedule, cost/risk; 3) Provide quarterly technical reports, participate in meetings, and present at conferences as required.

TIMETABLE

This project has a duration of 1 year, tentatively starting on December 1, 2022, with the timetable below.

Task/Subtask/Milestone Description	Start Date	End Date	2022	2023											
			12	1	2	3	4	5	6	7	8	9	10	11	12
Task 6 - Project Management and Planning	**12/01/22**	**11/30/23**	■	■	■	■	■	■	■	■	■	■	■	■	■
Milestones/Deliverables															
Kickoff Meeting		**01/01/23**													
Quarterly Report		**Quarterly**	x			x			x			x			
Final Technical Report		**12/30/23**													x
Task 7 - Evaluation and Characterization of Carbon Products	**12/01/22**	**05/31/23**	■	■	■	■	■	■							
Milestones/Deliverables															
Ranking of produced carbons and applicability in battery applications		**05/31/23**										x			
Task 8 - Process Model of Greener H_2 Production System	**06/01/23**	**11/30/23**							■	■	■	■	■	■	■
Milestones/Deliverables															
Software tool for sizing and integration of hydrogen production facilities		**11/30/23**												x	

BUDGET

The amount of $180,000 (50% matching funding) is requested from the NDIC. UND's portion of the NDIC funding ($80,001) will be used to cover a portion of UND's salary expenses ($21,499), associated fringe benefits ($6,257), and indirect costs ($30,352). UND's indirect charges are calculated based on the Modified Total Direct Costs (MTDC), at 41%, defined as the total direct costs of the project less individual items of equipment $5,000 or greater and subcontracts in excess of the first $25,000 for each award. The PI will travel to attend a DOE project progress meeting and $1,484.00 of funding will cover the flight ticket and other traveling expenses.

Other direct costs include sample analysis estimated at $5,835 with fees based on 87 test specimens: thermo-Gravimetric Analysis and Differential Scanning Calorimetry $1,470; Scanning Electron Microscope $980, Transmission Electron Microscopy $2,160; and Battery Performance testing $1,225. Subzero Energy LLC will provide consulting services in Task 7 for the battery assembly and testing ($14,394); and Subaward for Envergex LLC ($99,999).

Project Associated Expense	NDIC's Share for UND	UND (Cash via Federal Funding)	Total Project Cost
Personnel	$ 21,499		$ 21,499
Fringe Benefits	$ 6,257		$ 6,257
Travel	$ 1,484		$ 1,484
Equipment	$ -		$ -
Supplies	$ -		$ -
Other Direct Costs ($99,999 Subaward - Envergex LLC)	$ 120,228		$ 120,228
Indirect Charges	$ 30,532		$ 30,532
Total	**$ 180,000**	**$ 180,000**	**$ 360,000**
Total Cost Share	**50%**	**50%**	**100%**

Envergex is a subawardee under the companion Department of Energy project. UND will accordingly administer the $99,999 requested from the NDIC to Envergex as a subaward. The total value of Envergex's work for this project is $99,999, and the amount is requested from the NDIC. Envergex is requesting $48,082.00 for personnel, $26,089.00 for fringe benefits, $3,200.00 for travel, and $22,628.00 for indirect charges from the NDIC.

CONFIDENTIAL INFORMATION

Appendix F: Confidential Information.

PATENTS/RIGHTS TO TECHNICAL DATA

Any potentially patentable intellectual property (IP) generated in the proposed work will be promptly and thoroughly documented. Standard procedures currently in place at UND regarding IP protection and reporting will be followed. Personal privacy-related information will be protected and all other confidential information or potentially harmful information will have restricted or no access to members outside of the research team or the funding agencies.

STATE PROGRAMS AND INCENTIVES

NDIC projects:	**Award Name:**	**Period**	**Amount**
FY17-LXXXIII-210	Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks	3/1/2016 – 3/31/2019	$280,000
FY20-XC-222	Rare Earth Element Extraction and Concentration at Pilot	10/1/2019 - 3/31/2022	$900,000
R-046-056	Electrostatic Lubrication Filtration of Wind Turbine Oil	6/1/2021 - 11/30/2022	$286,234
FY21-XCIV-233	Electrostatic Filtration of Large Lubricant Reservoirs	2/1/2021 - 6/30/2022	$151,494
R-035-044	Preparation of Graphene-Modified $LiFePO_4$ Cathode for Li-ion Battery	3/1/2018 – 3/31/2020	$238,366
FY21-XCIV-232	Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes	2/1/2021 - 12/31/2022	$75,000
TOTAL FUNDING			**$ 1,412,728.00**

Appendix A: References

[1] CNT Composites. Cost and Production. https://sites.google.com/site/cntcomposites/cost-and-production

[2] Liu, X., Licht, G., Wang, X. and Licht, S., 2022. Controlled Transition Metal Nucleated Growth of Carbon Nanotubes by Molten Electrolysis of CO_2. Catalysts, 12(2), p.137.

[2] Bloomberg NEF, Hydrogen Economy Outlook, Key Messages, at 3 (Mar. 30, 2020), https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

[3] Monolith-Corp, 2022. Comparison of carbon intensity of SMR, Electrolysis and Pyrolysis. https://monolith-corp.com/process-comparison

[4] Li, Y., Li, D. and Wang, G., 2011. Methane decomposition to COx-free hydrogen and nano-carbon material on group 8–10 base metal catalysts: a review. *Catalysis today*, *162*(1), pp.1-48.

[5] Välimäki, E., Yli-Varo, L., Romar, H. and Lassi, U., 2021. Carbons Formed in Methane Thermal and Thermocatalytic Decomposition Processes: Properties and Applications. *C*, *7*(3), p.50.

[6] Idaho National Laboratory. Raven, 2022. https://raven.inl.gov/SitePages/Overview.aspx

Appendix B: Resumes of Key Personnel

Dr. Daniel A. Laudal, Director, Institute for Energy Studies, University of North Dakota (UND)

Education and Training

University of North Dakota	Chemical Engineering	B.S. 2006
University of North Dakota	Chemical Engineering	Ph.D. 2017
University of North Dakota	Master of Public Admin.	Expected 2023

Research and Professional Experience

2021-Present Director, UND Institute for Energy Studies (IES)

Leading the research and academic programs in Energy at the College of Engineering & Mines. Help realize the IES goal of developing UND into a premier "Energy University" that "inspires the creation of new knowledge to enable the development of revolutionary energy technologies, train the next generation of energy experts, and establish advanced industries required to make affordable emissions free energy technologies a reality". Responsibilities include identifying key technical and economic barriers to the development of secure, affordable, and reliable energy production technologies; identifying proposal opportunities and develop new relationships with potential partners; and drawing from resources across campus building teams to deliver the research, education, and outreach required to meet the needs of public and private partners.

2019-2021 Environmental Manager / Project Tundra Project Manager, Minnkota Power Coop

Led the environmental regulatory compliance and environmental planning efforts for a generation & transmission cooperative serving eastern ND and northwestern MN. As Project Tundra Project Manager, led Minnkota's development of a world-scale carbon capture and storage project for the Milton R. Yong Station, a lignite coal fired power plant in ND. Responsibilities included leading development of the design, permitting and financing of the carbon capture plant and geologic storage facility.

2016-2018 Manager: Major Projects, UND Institute for Energy Studies.

Primary roles included developing and writing funding proposals, managing research projects, coordinating IES research staff and students, and process design/development of innovative solutions to challenges in the energy industry. Principal Investigator or Project Manager or several DOE, State and industry funded projects. Research focused on the following major areas: carbon management for the power industry, production of co-products from coal and associated materials, value-added opportunities/technology development for North Dakota's energy industries.

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

Lead researcher or principal investigator on several federal, state and industry funded projects. Work involved early-stage R&D of novel processes and technologies, primarily focusing on laboratory- and bench-scale demonstrations. Areas of focus included chemical looping combustion and post combustion carbon dioxide capture.

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

Research involved design and operation of various lab and pilot-scale gasification, combustion and advanced power systems. Gained invaluable experience with high pressure and high temperature systems and fluidized beds.

<u>2006-2008 Field Engineer, Schlumberger Oilfield Services</u>.

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

Selected Publications

Benson, S., Srinivasachar, S, **Laudal, D**., Browers, B. "Evaluation of Carbon Dioxide Capture from Existing Coal Fired Plants by Hybrid Sorption using Solid Sorbents." Final Technical Report. US Department of Energy Award Number: DE-FE0007603. May 2015

Laudal, D., Benson, S., Addleman, S., Palo, D. "Leaching behavior of rare earth elements in Fort Union lignite coals of North America." International Journal of Coal Geology 191 (2018) 112-124.

Laudal, D., Benson, S., Addleman, S., Palo, D. "Rare earth elements in North Dakota lignite coal and lignite-related materials." ASME Journal of Energy Resources and Technology 140 (2018).

Park, D., Middleton, A., Smith, R., Deblonde, G., **Laudal, D.,** Theaker, N., Hsu-Kim, H., Jia, Y. "A biosorption-based approach for selective extraction of rare earth elements from coal byproducts." Separation and Purification Technology. Volume 241:116726. June 2020.

Mann, M; **Laudal, D.**; Benson, S. "Maintaining Coal's Prominence in a Carbon Constrained World." Conference Proceedings: 2017 International Conference on Coal Science and Technology and 2017 Australia-China Symposium on Energy. September 25-29, 2017. Beijing, China.

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, September 2019, pages 361-370.

Van der Watt, J.G., **Laudal, D**., Krishnamoorthy, G., Feilen, H., Mann, M., Shallbetter, R., Nelson, T., Srinivasachar, S. "Development of a spouted bed reactor for chemical looping combustion." Journal of Energy Resources and Technology. 140(11), 112002 (8 pages), November 2018.

Nelson, T., van der Watt, J.G., **Laudal, D**., Feilen, H., Mann, H., Srinivasachar, S. "Reactive jet and cyclonic attrition analysis of ilmenite in chemical looping combustion systems." International Journal of Greenhouse Gas Control. Volume 91, December 2019, 102837.

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

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

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

Patents

Laudal, D., Benson, S. "Rare earth element extraction from coal." U.S. Patent No. 10,669,610. March 2017

Theaker, N., **Laudal, D.,** Lucky, C. "Generation of rare earth elements from organically associated leach solutions." Provisional Application 63/112,842. November 2020.

Theaker, N., **Laudal, D**. "Method for leaching rare earth elements and critical minerals from organically associated materials." Provisional Application 63/112,846. November 2020.

Johannes George van der Watt

Research Engineer Institute for Energy Studies

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

Education and Training

University of North Dakota	Chemical Engineering	Ph.D., 2019
North-West University, South Africa	Chemical Engineering	M. Eng., 2013
North-West University, South Africa	Chemical Engineering	B. Eng., 2011

Research and Professional Experience

2019-Present Research Engineer, UND Institute for Energy Studies:

Conducts advanced research in chemical engineering, with specific focus on materials characterization, traditional and advanced energy generation, renewables, emissions control and energy storage. His responsibilities include developing proposals, performing economic and feasibility studies, conducting modeling and experimental work.

2015-2019 Graduate Research Assistant, UND Institute for Energy Studies:

Dr. Van der Watt's Ph.D. research focused on modeling and improving oxygen carrier performance in chemical looping combustion systems. He assisted in developing applications of engineering in materials characterization for advanced energy systems, emission control and energy storage sorbents. He excelled as a diagnostics and repair specialist on thermogravimetric analyzers and laser gas analyzers.

2013-2014 Junior Process Engineer, Pro-Op Industries (South Africa):

Dr. Van der Watt assisted in vibration sensor installation at ferrochrome plants to increase ball mill operability and compiled trial reports on the efficacy of vibration sensor installation by reviewing operating parameters and production data. He organized and conducted trial tests regarding an alternative fuel project at a leading South African cement producer. His day-to-day responsibilities included compiling detailed reports and progressive feedback on the outcome of the alternative fuel project trials, progress and post completion reports during cement plant shutdowns as well as planning and execution of operational tasks during cement plant shutdown. He conducted plant surveys for upgrade and installation of weigh feeders, online analysis equipment and kiln seals.

2012-2013 Graduate Research Assistant, North-West University (South Africa):

Part time lecturer of momentum transport for third year chemical engineering students. His Master's study focused on identifying possible and current flint clay uses. He examined the potential to expand or improve the marketability of the flint clay. He identified three highly viable applications within the chemical, cement and paint industries. The applications were examined to determine the exact technical and economic viability of each respective application.

Publications

- Nelson, T., **Van der Watt, J.G.**, Laudal, D., Feilen, H., Mann, M. and Srinivasachar, S., 2019. Reactive jet and cyclonic attrition analysis of ilmenite in chemical looping combustion systems. *International Journal of Greenhouse Gas Control*, 91, p.102837.

- **Van der Watt, J.G.**, Laudal, D., Krishnamoorthy, G., Feilen, H., Mann, M., Shallbetter, R., Nelson, T. and Srinivasachar, S., 2018. Development of a Spouted Bed Reactor for Chemical Looping Combustion. *Journal of Energy Resources Technology*, 140(11).
- Srinivasachar, S., Nelson, T., **Van der Watt, J.**, Feilen, H., Laudal, D., & Mann, M. (2018). *Methodology for Attrition Evaluation of Oxygen Carriers in Chemical Looping Systems: Final Scientific/Technical Report-Phase II* (No. DOE-Envergex-PhII-SC0011984). Envergex LLC.

Yong Hou, Ph.D.

Subzero Energy LLC

EDUCATION BACKGROUND

2002-2007	Ph. D., Management Science and Engineering
	University of Shanghai for Science and Technology
1989- 1992	Master of Science, Systems Engineering
	University of Shanghai for Science and Technology
1979-1983	Bachelor of Science, Electronics Engineering
	Hunan University of Art and Science

PROFESSIONAL WORKING EXPERIENCE

May 2022 – Present	President
	Subzero Energy LLC, Grand Forks, ND
2017- Apr. 2022	Research Engineer
	Institute for Energy Studies, University of North Dakota
2008 - 2012	Adjunct Professor
	College of Business & Public Administration, University of North Dakota
2007- 2008	Vice President of Product Development
	Neosonic Li-Polymer Energy (Zhuhai) Corporation
1995-2002	Founder/General Manager
	Shanghai Zhongdian International Company
1983-1995	Electronics Engineer
	Hunan Puyuan Engineering Machinery Company

GRANTS

1) Business and Public Administration & Law Funding, UND: Development of a Site Assessment Instrument for Small Wind Turbine Development in North Dakota. Co-Investigators, $4,835, 2011
2) Research ND, Venture Grant Phase I/II: A Low Cost and Reproducible Synthetic Procedure for Mass Production of Lithium Iron Phosphate Cathode Materials for Lithium Ion Batteries, Co-Investigator, $148,105, 2016
3) Renewable Energy Program, North Dakota Industrial Commission: Preparation of Graphene-Modified $LiFePO_4$ Cathode for Li-Ion Battery. Co-Investigator, $486,238, 2018

4) Agriculture Products Utilization Commission, Department of Agriculture: Advanced Integrated Solar-LFP Battery Powered Pump System for Remote Farm Fields. Principal Investigator, $15,000, 2018

5) Post-Doctoral Program, UND: Lignite-Derived Graphene/Si Nanocomposite Anode for Lithium Ion Battery, Co-Investigator, $140,000, 2019

6) Chung Fo Century Technology: Improve Electrical Conductivity of Substrate Materials for Bipolar Plate Lead-Acid Battery, Principal Investigator, $89,336, 2019

7) DOE-NETL University Coalition for Fossil Energy Research: Porous Silicon/Lignite-Derived Graphene Composite Anodes for Lithium-Ion Battery, Key Personnel, $369.581, 2019

8) Mic-Power New Energy Co., Ltd: The Preparation of a High Capacity Graphene Modified Graphite /SiOx Anode Electrode, Principal Investigator, $259,769, 2020

PATENTS

A Hybrid control system for Electric Bicycle (CN Patent 2017 2050 8455 .3)

PUBLICATIONS

1. Yong Hou and Luke Huang. "**The Present State of and a Suggested Inserting Point for Biodiesel Production Industrialization in China"**, 2006 IEEE International Conference on Service Operations and Logistics, and Informatics Proceedings, Page 679-683, ISBN: 1-4244-0318-9 (EI Accession Number: 074610921148), June 2006.

2. Yong Hou and Fuyan Xu. "**The Development of Biodiesel Industrialization"**, Commercial Research, ISSN: 1001-148X, October 2006.

3. Jinrong Zhen and Yong Hou. "**Research on an Evaluation Model of Technique Innovation"**, 2006 IEEE International Conference on Service Operations and Logistics, and Informatics Proceedings, Page 187-191, ISBN: 1-4244-0318-9, June 2006.

4. Luke Huang and Yong Hou. "**Manufacturing information recognition, analysis, and simulation using Windows based programs"**, The 5th Wuhan International Conference on e-Business: Integration and Innovation through Management, Vol. 3, pp1931-1937, May 2006.

5. Zheng Jin-rong, Xu Fu-yuan, Hou Yong, "**The Selection of Stock Options for Venture Firms**", Commercial Research, 2006.18,1-5

6. Yong Hou, Fuyuan Xu and Wei Cheng, "**A Sustainable Growth Model with the Utilization of Renewable-Energy"**, 2007 IEEE International Conference on Communications, Services, Knowledge and Engineering, Page 5012-5015, ISBN: 1-4244-1311-7, September 2007.

7. Yong HOU, Fu-yuan XU, Wei CHENG. **"A Microeconomic Model of Optimized Investment Project on the Substitution of Renewable Energy"**, Commercial Research, 2008-05.

8. Yong Hou, Fuyuan Xu and Wei Cheng. **"A Sustainable Growth Model Based on the Substitution of Renewable Energy",** Systems Engineering – Theory & Practice, Vol. 28 (9): 67-72, September 2008.

9. S.M. Hanson, A.L Johnson, Yong Hou, M.D. Hellwig (2012). "**Recharging Centers for Disease Control Light Trap Batteries with Solar Panel"**: International Journal of Applied Science and Technology, Vol.2 No.7, September 2012.

10. Yong. Hou, Y. Peng, A.L. Johnson, J. Shi (2012). "**Empirical Analysis of Wind Power Potential at Multiple Heights for North Dakota Wind Observation Sites":** Energy Science and Technology ISSN 1923-8460 [Print] ISSN 1923-8479 [Online] Vol.4 No.1, August 2012.

11. Yong Hou, Jing Shi and Alex Johnson; **Empirical analysis of capital accumulations in constant price and the role of energy consumption on China's economic growth**, International Green Energy Conference, IGEC-2016-1017, May, 2016

12. Weidong Wu, Jun Wu, Jiawei and Yong Hou; **Absorption properties of ionic liquids-CO2 as new working pairs used for absorption refrigeration system powered by low-grade heat energy**, International Green Energy Conference, IGEC-2016-1022, May, 2016

13. Weidong Wu, Yong Hou, Jun Wu and Lin Su; **Predicting phase behavior of CO2 and imidazole ionic liquids as new working pairs in absorption refrigeration system using GC-EOS method**, International Journal of Thermal Sciences, June 2016

14. Hongbo Zhu, Yan Gao Yan and Yong Hou; **Real-time pricing strategy for smart grid based on Markov decision processes**, Systems Engineering Theory and Practice, Nov. 2017

15. Weidong Wu, Li Peng; Yong Hou; Lin Su; Hua Zhang; **An experimental investigation on the solubility characteristics of CO2-ionic liquids as new working pairs used for absorption refrigeration systems**; The Journal of Chemical Thermodynamics, Jan, 2018.

16. Hongbo Zhu, Yan Gao and Yong Hou; **Real-Time Pricing for Demand Response in Smart Grid Based on Alternating Direction Method of Multipliers**; Mathematical Problems in Engineering, vol. 2018, Article ID 8760575, 10 pages, 2018. doi:10.1155/2018/8760575.

17. H.B. Zhu, Y. Gao, Y. Hou, and L. Tao; **Multi-time slots real-time pricing strategy with power fluctuation caused by operating continuity of smart home appliances**; Engineering Applications of Artificial Intelligence; Engineering Applications of Artificial Intelligence, May 2018, Vol.71, pp.166-174

18. Hongbo Zhu, Yan Gao, Yong Hou, Zongyao Wang, Xue Feng; **Real-Time Pricing Considering Different Type of Smart Home Appliances Based on Markov Decision Process**; International Journal of Electrical Power and Energy Systems, May, 2019

SRIVATS SRINIVASACHAR, Ph.D.

Envergex LLC

Education and Training

2003-2004	Boston University, School of Management Master of Business Administration	Boston, MA
1981-1986	Massachusetts Institute of Technology Sc.D. degree in Chemical Engineering	Cambridge, MA
1976-1981	Indian Institute of Technology Bachelor of Technology, Chemical Engineering	Chennai, India

Research and Professional experience

2006 – Present: President, Envergex LLC, Sturbridge, MA:

- Mitigation of aerosol emissions from solvent-based CO_2 capture systems (Phase I STTR) - 06/16
- Developing novel materials for capturing CO_2-US DOE (Phase I/II STTR) grant (Aug. 2014)
- Developed a novel method for capturing CO_2 from flue gas (CACHYS™) - awarded a US Department of Energy grant (June 2010) DOE Phase I STTR; Commercializing CACHYS™ technology - teaming with University of North Dakota on a $ 3.6 million USDOE program
- Manufactured and supplied commercial quantities and successfully demonstrated ESORB-HG® sorbent to several power utility and industrial customers at full-scale
- Teamed with UND and utility partner to perform engineering and costing to implement an innovative technology: activated carbon manufacturing integrated to a power plant

1999 – 2006: ALSTOM Power, Inc. (1993 – 1999: ABB Combustion Engineering, Inc. Windsor, CT):

- Technical Manager, Environmental Control Technology (March 2003-2006). Led product development team, successfully scaled-up technology, executed three (3) commercial demonstration projects, and implemented the product at commercial scale.
- Principal Consulting Engineer, New Product Business Development (Oct. 1999 to March 2003)
  - Multi-business product development for control of SO_2 emissions from power plants
- Environmental Group Leader, (Oct. 1997 – Sept. 1999)
- Senior Consulting Engineer, (1994 – 1997) - Project Leader on environmental and heat recovery projects and developed high-performance fuel nozzles for boilers to reduce nitric oxide emissions

1986-1993: Physical Sciences Inc. Andover, MA:

- Manager, Environmental Remediation and Resource Utilization (1992-93) - Secured and managed an EPA Superfund project to remediate heavy metal-contaminated soils.
- Principal Research Scientist (1986-92) - PI on a multi-million dollar university-industry project - created test methods and software for electric utilities to evaluate savings with various fuel switching options and predict fuel quality impacts on deposition in coal-fired power plants

Patents (Selected) – 16 Patents

U.S. Patent 9,624,109, “Method of manufacturing carbon-rich product and co-products”

U.S. Patent 8,080,088, “Flue gas mercury control”

Publications (Selected)

1. Mustonen, J., Pohjola, J., Porle, K., Mauritzson, C., **Srinivasachar, S.**, Kauppinen, E., Lind, T., Schleicher, B., Kurkela, J., Joutsensaari, J., Valmari, T., Tapper, U., & Ylätalo, S. (1999). Ultrafine ash emission control of pulverized coal-fired boilers with electrostatic precipitators. In R. Thun, & M. Korhonen (Eds.), *Energia- ja ympäristöteknologia. Tutkimusohjelman vuosikirja 1998: Projektiesittelyt* (pp. 289-312). VTT Technical Research Centre of Finland. VTT Symp. No. 191.
2. Pease, B R, **Srinivasachar, S**, and Porle, K. Ultra-high efficiency ESP development for air toxics and fine particulate removal -- Phase 1 mercury removal investigations. United States: 1998.

Appendix C: Letter of Commitment

Envergex LLC
10 Podunk Road
Sturbridge, MA 01566

July 28, 2022

Dr. Johannes van der Watt
Research Engineer | Institute for Energy Studies
University of North Dakota
2844 Campus Rd. Stop 8153
Collaborative Energy Complex Room 246D
Grand Forks, ND 58202-8153
johannes.vanderwatt@und.edu
O: (701) 777-5177 | C: (701) 739-4696

Re: Support of the proposal entitled "Production of Hydrogen and Valuable Carbons from Methane-Sources".

Dear Dr. Van der Watt,

This letter confirms Envergex LLC's commitment to support your proposed efforts to produce hydrogen and carbon-based battery constituents using biomethane. I understand the project will determine how a stable hydrogen manufacturing process can be maintained using intermittent wind power for energy provision. I am confident that our process modeling and optimization expertise will help UND design the best integration strategy and ensure more environmentally friendly hydrogen production.

Envergex will provide support to the project to accomplish the following additional tasks intended to complement the original five tasks of the companion Department of Energy project:

Task 6 Project Management and Planning: The purpose of this task is coordination and planning of the project. Envergex will support UND to address all items related to monitoring and control of project scope, cost, and schedule. Envergex will provide input for quarterly technical reports, topical reports, participate in meetings and make presentations at conferences as required.

Task 7 – Evaluation and Characterization of Carbon Products: In this task, UND will use the carbons produced from the companion project's laboratory-scale thermocatalytic methane conversion system and characterize their physical and chemical properties. The carbons that are formed during this process could have potential for use in lithium-ion battery electrodes. The project team will produce, collect and characterize these carbons to see if they exhibit the characteristics of high quality carbon nanotubes (CNTs). The focus of this task is to find the operating conditions that yield high quality carbon (e.g. carbon nanotubes –CNTs) with or without further purification for use in battery manufacturing. The goal is to assess whether the conditions that maximize hydrogen production also correspond with high quality CNT synthesis. UND will lead this task, relying on their experience in battery manufacturing and testing.

Task 8 – Process Model of Greener H_2 Production System: In this task, Envergex will develop a software toolkit that uses variable grid prices for electricity as input along with detailed capital and operating costs for hydrogen production, storage and utilization options. In addition, we will evaluate the net present value of investments into the proposed hydrogen manufacturing process across different future scenarios. Envergex will lead this task, relying on techniques and models developed in research projects funded by the Department of Energy for energy storage applications within the utility sector (DE-SC0020863 and DE-SC0021728).

The estimated period of performance is 12 months, starting on or about December 1, 2022. The total value of Envergex's work for this complementary project is $99,999. The $99,999 is requested from the NDIC. The matching funds ($99,999) will come from our existing U.S. Department of Energy budget.

Envergex is committed to developing, testing, and commercializing advanced energy generation and environmental control technologies. The development of a low-cost technology for hydrogen production and additional production of specific carbons for energy storage for the electricity grid is a critical need for the U.S. to maintain a diverse fleet of electricity supply, and Envergex is pleased to be a participant in the subject proposal.

If you have any questions or comments, please feel free to contact me by phone at (508) 347-2933 or by e-mail at srivats.srinivasachar@envergex.com. I look forward to this opportunity to team with the University of North Dakota.

Sincerely,

Srivats Srinivasachar
President
Envergex LLC

Appendix D: Letter of Interest

Clean Republic SODO LLC
920 South Holgate Street, Suite 106 – Seattle, WA 98134
www.cleanrepublic.com – ops@cleanrepublic.com

January 28, 2022

Dr. Johannes van der Watt
University of North Dakota
2844 Campus Rd. Stop 8153
Collaborative Energy Complex Room 246D
Grand Forks, ND 58202-8153
johannes.vanderwatt@und.edu
O: (701) 777-5177 | C: (701) 739-4696

Re: University of North Dakota proposal entitled "Production of Hydrogen and Valuable Carbons from Methane-Sources"

Dear Dr. Van der Watt:

Clean Republic LLC is highly interested in the concept proposed by the University of North Dakota – Institute for Energy Studies and project partner Envergex LLC to produce biogas-derived carbon materials for use in lithium-ion batteries (LIBs). We understand that the team intends to produce carbon nanotubes (CNTs) and evaluate their performance and suitability as electrode-constituents in LIBs. CNTs are highly favored for use in anodes and cathodes of lithium-ion batteries, but they are costly to manufacture. Clean Republic believes the proposed technology has the opportunity to lower the cost of LIBs because of the project team's unique CNT production process. Their feedstock choice, coupled with carbon dioxide-free hydrogen and carbon production, aligns with our company's strategy focusing on clean-tech products and manufacturing.

Clean Republic is a North Dakotan-based company that markets clean energy-relevant products, including LIB packs, electric bikes, solar water heating panels, and related products to the public. Dakota Lithium, one of Clean Republic's trademark products, generated over $18-million in revenue in 2021. Clean Republic has over ten years of experience in the entire supply chain of lithium-ion batteries, and we have built unique industry networks with material suppliers and cell manufacturers worldwide.

Our company is willing to engage with the project team and discuss relevant battery specifications and material requirements. In addition, we will gladly facilitate discussions between the project team and our network of suppliers and manufacturers to evaluate the market potential for this unique CNT product. If successful, we would consider support for further development and implementation of the technology.

If you have questions or require additional information, please contact Dr. Yong Hou, at hou@cleanrepublic.com.

Sincerely,

Michael Shope

CTO – Clean Republic

Clean Republic SODO LLC
920 S. Holgate Street, Suite 106 – Seattle, WA 98134
www.cleanrepublic.com -- ops@cleanrepublic.com – (800) 460-0890 Ext: 705

Appendix E: Tax Liability Statement

Industrial Commission

Tax Liability Statement

Applicant:
University of North Dakota

Application Title:
Production of Hydrogen and Valuable Carbons from Methane Sources

Program:

- ☐ Lignite Research, Development and Marketing Program
- ☑ Renewable Energy Program
- ☐ Oil & Gas Research Program
- ☐ Clean Sustainable Energy Authority

Certification:
I hereby certify that the applicant listed above does not have any outstanding tax liability owed to the State of North Dakota or any of its political subdivisions.

Karen Katrinak

Signature
Karen Katrinak
Proposal Development Officer

Title

August 1, 2022

Date

Appendix F: Confidential Information