APPLICATION CHECKLIST

Use this checklist as a tool to ensure that you have all of the components of the application package. Please note, this checklist is for your use only and does not need to be included in the package.

☒	Application
☒	Transmittal Letter
☒	$100 Application Fee
☒	Tax Liability Statement
☒	Letters of Support (Appendix C)
☒	Other Appendices (Appendix A, Confidential Information)

When the package is completed, send an electronic version to Ms. Karlene Fine at kfine@nd.gov, and 2 hard copies by mail to:

Karlene Fine, Executive Director
North Dakota Industrial Commission
State Capitol – 14th Floor
600 East Boulevard Ave Dept 405
Bismarck, ND 58505-0840

For more information on the application process please visit:
http://www.nd.gov/ndic/renew/info/submit-grant-app.pdf

Questions can be addressed to Andrea Pfennig at 328-3786.

Renewable Energy Program

North Dakota Industrial Commission

Application

Project Title: Flexible Direct Air Capture System – Flex-DAC™

Applicant: University of North Dakota

Principal Investigator: Junior Nasah

Date of Application: July 31, 2022

Amount of Request: $499,452

Total Amount of Proposed Project: $1,670,138

Duration of Project: 2 Years

Point of Contact (POC): Junior Nasah

POC Telephone: 701-777-4307

POC Email: nasah.domkam@und.edu

POC Address: 2844 Campus Road Stop 8153

Grand Forks, ND 58203-8153

TABLE OF CONTENTS

ABSTRACT

Objective

The objective of the proposed project is to develop a direct air capture technology that leverages the low cost of renewable energy power prices to economically capture carbon dioxide directly from air. The proposed technology will use optimization models and thermal energy storage to enable flexible, low-cost direct removal of CO_2 from ambient air in a process we call Flexible Direct Air Capture (Flex-DAC™). The project builds on the patented CACHYS™ sorbent technology of small business Envergex LLC, previously developed at the University of North Dakota, and is seeking to integrate the capture technology with an energy storage system.

Expected Results

Our technology provides specific benefits to the State of North Dakota as key components can be manufactured using North Dakota (ND) biomass or coal. For large scale applications (100,000 or more tons CO_2 captured per year) the captured CO_2 can be permanently stored underground given the extensive carbon storage potential of ND. For smaller applications (~10,000 tons CO_2/yr) the captured CO_2 can be used for high value projects such as carbon mineralization (soil amendments), greenhouse gases, green cement manufacturing and the food industry. This project is in line with ongoing efforts by the State of North Dakota to become a host for one of the four national Direct Air Capture Hubs[i].

Duration

24 months (suggested: 01/01/2023 - 12/31/2024)

Total Project Cost

$499,452 requested from NDIC and $1,670,138 for total project cost.

Participants

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

PROJECT DESCRIPTION

Objectives

The objective of the proposed project is to develop the next generation application of the proprietary patented E-CACHYS™ technology (patent number US8840706B1[ii]), by optimizing the sorbent for direct removal of CO_2 from ambient air in a process referred to as Flexible Direct Air Capture (Flex-DAC™). Project activities will include 1) process modeling to optimize and design a renewable energy storage system integrated with our Flex-DAC™ process, 2) construction and testing of a pilot CO_2 absorber system capable of capturing 240 lbs of CO_2 a day, and 3) a conceptual design of a commercial (10,000 and 100,000 metric tons CO_2/year) flexible DAC system. In a separate project funded by the Department of Energy's Advanced Research Project Agency – Energy (ARPA-E), award DE-AR0001314[iii], this team is developing a "flexible" iteration of the E-CACHYS™ technology to be deployed on ***natural gas combined cycles***. The team is seeking to match $1.2 million of the ARPA-E award with this project. Specifically:

- With the ***ARPA-E matching funds***, the team has developed process and costing models, and will complete a conceptual engineering design of the CACHYS™ technology and pilot unit focused on optimizing the capture of ***point source CO_2 from natural gas combustion (~4% CO_2 composition).***
- Under ***this proposed project***, the team will modify the models to include DAC and build a separate pilot adsorber system for ***capturing CO_2 directly from air (~0.04% CO_2).***

In order to achieve cost effective carbon neutral energy generation, it is vital to develop Negative Emission Technologies such as direct air capture (DAC). Current estimates for capturing CO_2 directly from air range from $82 to over $600 per metric ton, however, the federal target per the Department of Energy is ***$100 per metric ton of CO_2 equivalent***. This proposal seeks to develop a low-cost, sorbent-based technology with a CO_2 capture cost that is less than $100/metric ton CO_2. We will achieve this by adopting: 1) Passive capture of CO_2 from air. At a 0.04% concentration of CO_2 in air, active capture requiring fans to circulate air can be a significant operating cost. Our sorbent eliminates the need for fans. 2) Low-cost of our sorbent, estimated at $2 – $5 per kilogram, which is an order of magnitude lower than current estimates ($15 to $50 per kilogram), 4) Flexible regeneration using low-cost renewable energy from renewable farms or from the grid during instances of high renewable generation.

Methodology

Technology Background: During initial development of the E-CACHYS™ sorbent for coal-fired CO_2 capture, the project team observed that the freshly manufactured sorbent would become fully loaded during storage, suggesting active capture from the atmosphere. Proof-of-concept to verify this behavior was performed by the team by spreading freshly sorbent on a sieve and collecting samples at regular intervals to verify CO_2 uptake, see Figure 1. **The sorbent showed a CO_2 uptake of ~5% CO_2** from a simple direct exposure with no need for fans or blowers. *Additional testing results on the DAC capture performance have been very promising and are presented in the confidential appendix.*

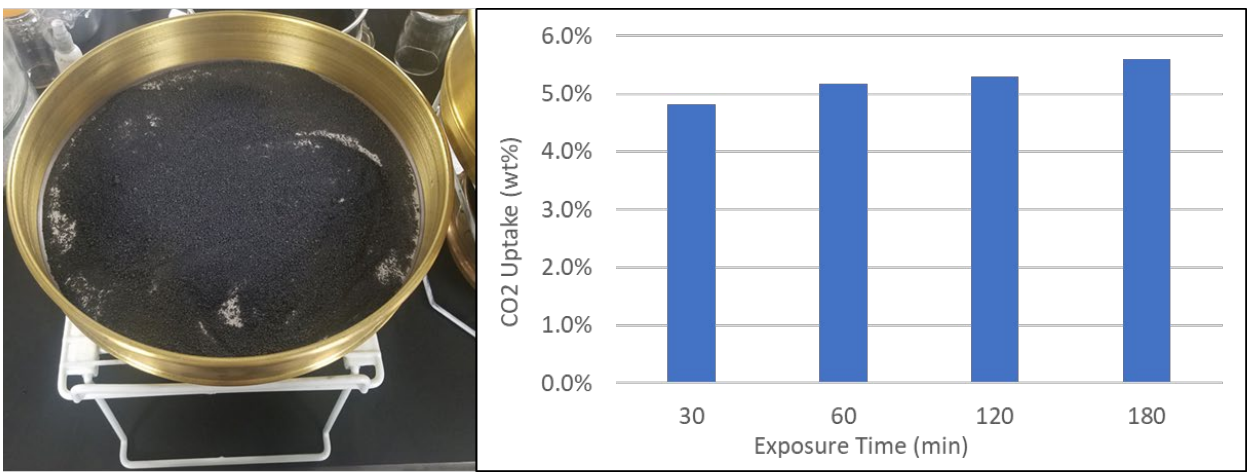


Figure 1. CO_2 uptake performance (right) from spreading E-CACHYS™ Sorbent on a sieve (left)

Synergistic Benefits of Proposed Match Funds: We are proposing to leverage funds from the complementary ARPA-E project, where the team has developed modelling tools to quickly evaluate and optimize the net present value (NPV) of a flexible E-CACHYS™ process installed on a natural gas-fired combined cycle (NGCC) power plant. In this project, we will modify those already developed models to focus on direct air capture configurations of the E-CACHYS™ technology. Also, under the ARPA-E award, we plan to build a pilot capture process designed for capturing natural gas combustion CO_2. The pilot unit will target 240 lbs of CO_2 per day, will include an adsorber (designed for ~4% CO_2 concentrations), and a sorbent regenerator.

Alternatively, in this project, we will develop a DAC adsorber designed for ultra-low CO_2 concentrations (***0.04%***) and compatible with the sorbent regenerator developed under the ARPA-E award. These synergies are key for reducing the cost of developing a DAC version of the E-CACHYS™ technology platform. *The detailed technical description of the proposed technology is confidential and attached as an appendix. The information provided is for review and evaluation purposes only***.**

Scope of Work: The proposed project will be executed under four tasks described below:

Task 1.0 – Model Development and Flex-DAC™ NPV Optimization: In this task, we will modify our existing models to include a Flex-DAC™ module. We will then optimize the Flex-DAC™ process by integrating a renewable driven thermal energy storage (TES) system with the Flex-DAC™ process. *Sub-task 1-1 – Electricity Pricing Model Development*: We will adopt the electric pricing data series generated by the Massachusetts Institute of Technology GenX model[iv] to forecast grid pricing on the MISO grid as a result of renewables penetration. An annual electric pricing profile will then be developed to identify instances of very low electricity pricing which coincides with high renewable energy production. *Sub-task 1-2 – NPV Optimization of Flex-DAC*™: In this task, models of the CACHYS™ system developed under the ARPA-E award will be modified to create a Flex-DAC™ model integrated with a TES system. An NPV optimization will then be performed by leveraging instances of very low electricity prices (high wind and solar production) to regenerate our CACHYS™ sorbent and keep operating costs of the technology low. We will vary energy storage size, regeneration rates and sorbent cyclic capacity to identify the optimal configuration for Flex-DAC™, and quantify the carbon budget. We will continue our discussions with Steffes Corporation to adapt their Electro-Thermal Storage (ETS) to our technology.

Task 2.0 – Design and Construction of Pilot DAC Absorber Module: *Sub-task 2.1 – Bench Scale Kinetics and Thermodynamics Evaluation of Sorbent*: In this task, we will fully evaluate capture performance of a bench top adsorber designed as a mini-module (~100 g of sorbent) of the process and identify relevant process parameters for pilot testing. Table 1 summarizes test conditions.

Table 1. Parametric Test Conditions in TGA-DSC

	Adsorption Cycle	Desorption Cycle
Temperature	5°C – 50°C	20°C – 140°C
Pressure	1 atm	0.1 – 1 atm
Gas Moisture Content	0 to ~95% relative humidity	0-100% steam

Sub-task 2.2 – Construction of Pilot DAC Adsorber Module: In this task the adsorber module for capturing CO_2 from air will be constructed. The design of the adsorber will focus on passive contact of air and sorbent, and integration with the regenerator system. Note, the matching funds will be used to develop a pilot system consisting of a sorbent regenerator system and an ***active adsorber*** (CO_2 concentrations of 4 – 14% at high pressure drops of ~30 – 60 inches of water). This project will develop a ***passive adsorber*** designed for air concentrations of CO_2 (0.04%) and operating at negligible pressure drops (~100 pascals). We will ***leverage the regenerator*** developed in the ARPA-E project to regenerate the sorbent.

Task 3.0 – Pilot-scale testing of DAC Adsorber: This task will evaluate the capture (adsorption and desorption) of CO_2 at a pilot scale (10 lbs./hr of CO_2). We will manufacture fresh sorbent for the DAC application. UND and Envergex have experience manufacturing several tons of the sorbent in previous work[v]. Table 2 summarizes the factors that will be investigated specifically moisture and temperature.

Table 2. Parametric Test Conditions in Bench Unit

Factor	Factors	Objective and Levels
Adsorption	Temperature, Humidity	2 levels per factor; Evaluate effect of changing atmospheric conditions on capture
Desorption	Pressure, Temperature	Number of levels TBD; Minimize regeneration duty
Cyclic Capacity	CO2 loading	2 levels; Sensitivity of loading to process feasibility

Task 4.0 – Commercial Process Design and Economic Evaluation: A preliminary commercial system design including engineering drawings for the absorber, regenerator and energy storage system will be developed at a scale of 10,000 and 100,000 metric tons of CO_2 captured per year to compare the benefits of a modular distributed approach and a large-scale capture facility respectively. A business plan for both applications will be developed to identify a commercial pathway for North Dakota deployment.

Anticipated Results

Project success will be measured by a successful pilot demonstration of direct air capture at 10 lbs/hr, demonstration of a high cyclic capacity under DAC conditions of ~100 g CO_2 per kilogram sorbent, which is up to 50% higher than the recommended capacity of 66 g CO_2 / kg (1.5 mol/kg)[vi]; a preliminary commercial-scale design of a 10,000 tonnes and 100,000 tonnes of CO_2 per year facility including a business case for developing the technology using North Dakota resources. The state of North Dakota is a strong candidate to host one of the four national DAC hubs to be funded under the Bipartisan Infrastructure Law[i]. If successful, the business case for the proposed Flex-DAC™ technology will be strengthened as it would facilitate deployment of CO_2 storage.

Facilities

UND has exceptional analytical, laboratory, and fabrication facilities including a mechanical/electrical fabrication shop. UND's recently acquired DRACOLA lab is a fully equipped fabrication facility suitable for fabrication of large pilot system equipment including installation and testing. UND Advanced Materials Characterization Laboratory (AMCL) analytical capabilities will be leveraged to characterize the physical/chemical properties of the manufactured sorbent.

Resources

UND has all the equipment required for evaluating the performance of the sorbent at a bench scale including two TGA/DSC systems for determining capacity and heat of reaction and mini-fluidized bed test system that can be modified for bench top regeneration testing of the CO_2-rich sorbent.

Techniques to be Used, their Availability and Capability

Sorbent Manufacturing: The team has experience with sorbent manufacturing including previous production of over 2 tonnes of material for original pilot testing work during development of the E-CACHYS™ process. The sorbent preparation methods are proprietary and provided in appendix for review.

Sorbent Chemistry Evaluation: The sorbent chemistry and capture mechanism is well understood by the project team at higher CO_2 concentrations of 4 to 14%. However, the low CO_2 concentrations in air present a unique challenge for kinetics and adsorption evaluation. A micro-module adsorber unit will be fabricated and combined with a CO_2/H_2O ppm analyzer from LI-COR to evaluate performance.

***Process Modelling**:* Envergex LLC has developed multiple python-based NPV optimization models that integrate flexible E-CACHYS™ technology's technical performance with its economic performance. With this model, the economic performance (NPV) of hundreds of different permutations of the E-CACHYS™ system design can be evaluated in minutes. The model will be updated to include a thermal energy storage system for regeneration of the E-CACHYS™ sorbent and a passive adsorber for DAC. Multiple electric pricing forecasts will then be used to evaluate the optimal design of the system for DAC.

Pilot Scale Testing: The team will leverage pilot scale development work under the ARPA-E project to develop a passive adsorber and regenerator. The team originally developed the E-CACHYS™ technology with a pilot demonstration at the same scale anticipated here – 10 lbs./hr of CO_2 captured, and with the lessons learned from that work, the team is suitably qualified to ensure success of the proposed pilot system.

Environmental and Economic Impacts while Project is Underway

No environmental or economic impacts are anticipated during project execution.

Ultimate Technological and Economic Impacts

A detailed review of direct air capture by the National Academies Press shows our proposed sorbent meets key factors required to achieve sorbent-based CO_2 capture under $100/metric ton when coupled with renewable energy sources[vii], as shown in Table 3 below:

Table 3. Technological Impact of Proposed Technology

Parameters	NAP Best Case Scenario[vi]	CACHYS™ Current Estimate	CACHYS™ Proposal Target
Sorbent cost ($/kg)	15	2 - 5	2
CO_2 Capacity (mole CO_2 / kg sorbent)	1.5	4	4
Cyclic Capacity (% wt.)	6%	4%	8-10%

Envergex LLC, the private partner developing the technology, will also evaluate economic benefits of developing other small niche applications (greenhouse gas, food industry) in the state of North Dakota. Envergex is aware of efforts at the state to establish a DAC hub and is strongly interested to join these endeavors to de-risk the technology commercialization pathway of Flex-DAC™ technology.

Why the Project is Needed

The ultimate benefit of developing this DAC technology is the vital role Negative Emissions Technologies (NET) play towards achieving a net-zero carbon grid. Work done at MIT[viii] estimates that trying to achieve a carbon-free grid ***with no fossil fuels could result in electricity prices more than doubling***. Achieving a

CO_2 – free national grid will require NET systems that remove CO_2 from the atmosphere. This is of specific importance and value to the state of North Dakota which boasts significant renewable and fossil resources and is a net energy exporter. Our technology fits within the State's goal to make ND a world leader in CO_2 storage given the unique geology of the state and its suitability for CO_2 sequestration. Additionally, we will use local resources such as biomass and ND lignite to manufacture the sorbent. Finally, the spent sorbent from the DAC process is expected to qualify as a fertilizer.

STANDARDS OF SUCCESS

The success of this project will be evaluated by the following measurable deliverables: 1. Preliminary design of both a small- and large-scale capture facility for the sorbent including a business plan for deployment in ND, 2. Development of a sorbent with stable cyclic capacity of 10 wt.% CO_2, 3. Stable long-term cyclic performance (> 500 cycles) of sorbent without replacement, 4. Development of a final sorbent cost less than $5/kg, 5. Evaluation of the kinetics of adsorption of the sorbent

BACKGROUND/QUALIFICIATIONS

UND and Envergex LLC have collaborated on multiple carbon capture projects, including the successfully completed 3-year, $3.6 million pilot-scale effort to evaluate the CACHYS™ carbon capture technology (DE-FE0007603[ix]), and DOE-STTR project[x] and E-CACHYS™ (DE-SC0010209[xi]), led by Envergex. The team is currently collaborating on the matching fund ARPA-E award (DE-AR0001314).

Dr. Daniel Laudal, Director – UND Institute for Energy Studies. As the recently appointed Director of the Institute, Dr. Laudal oversees the entire project portfolio of the institute and brings a strong expertise in energy. He previously held the role of Environmental Manager at Minnkota Power and managed Project Tundra, one of the largest CO_2 capture projects in the world. Prior to his role at Minnkota Power, he was the lead technical researcher on the development and pilot demonstration of the E-CACHYS™ technology.

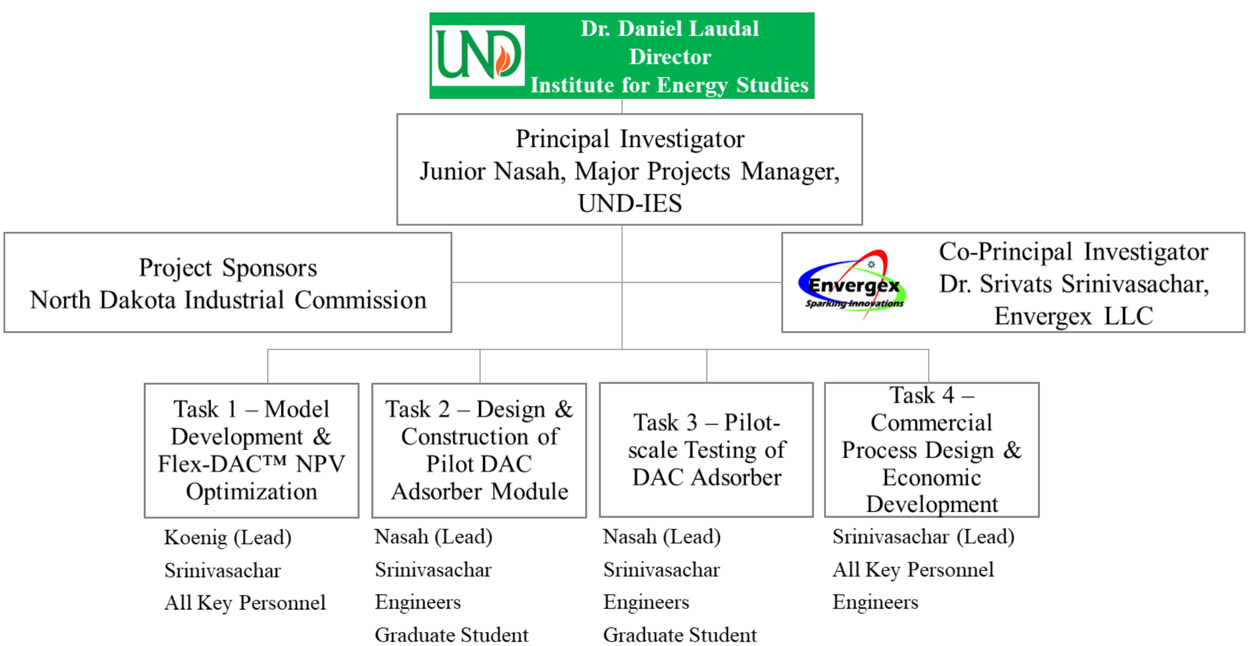
Principal Investigator: Mr. Junior Nasah, Manager Major Projects – UND Institute for Energy Studies will manage UND's activities and be the lead for Tasks 2 and 3. Mr. Nasah's expertise includes air pollution control and recently was PI on a DOE $1.9 million chemical looping combustion technology (DE-

FE00031534[xii]). Mr. Nasah is also the PI of University activities on the current ARPA-E matching project.

Srivats Srinivasachar, President, Envergex LLC, will be a technical advisor and a co-principal investigator. He is the developer of the E-CACHYS™ sorbent technology and holds multiple patents for development of activated carbons. He has had a long career in the power industry (13 years at ABB Combustion Engineering, subsequently ALSTOM Power, Inc. and now GE, and 13 years at Envergex LLC) and received his doctoral degree in Chemical Engineering at Massachusetts Institute of Technology. He is the PI and lead on DE-AR0001314 ARPA-E funded project.

Mr. Aaron Koenig, Envergex LLC, is a research scientist for Envergex LLC and the developer of the E-CACHYS™ NPV optimization models for award DE-AR0001314 with ARPA-E. He holds a M.Sc. in Chemistry with a focus on computational chemistry and analytical techniques. He is currently pursuing a Ph.D. in Chemical Engineering and will be the lead for Task 1.

MANAGEMENT



TIMETABLE

Task/Subtask/Milestone Description	Start Date	End Date	2023 Q1	2023 Q2	2023 Q3	2023 Q4	2024 Q5	2024 Q6	2024 Q7	2024 Q8
Task 1 - Model Development & NPV Optimization	01/01/23	06/30/23								
Milestones/Deliverables										
Quarterly Reports										
Model Development Completed		03/31/23								
NPV optimized Flex-DAC™ Design		06/30/23								
Task 2 - Design and Construction of Pilot DAC Adsorber	04/01/23	09/30/23								
Quarterly Reports										
Design of pilot adsorber completed		06/30/23								
Construction of Pilot Test Unit; Sorbent Manufactured		09/30/23								
Task 3 - Pilot Unit Testing	*10/01/23*	06/30/24								
Milestones/Deliverables										
Quarterly Reports										
Parametric testing Completed		01/31/24								
Continuous testing Completed		06/30/24								
Task 8 - Commercial Process Design & Economic Evaluation	07/01/24	12/31/24								
Milestones/Deliverables										
Quarterly Reports										
Design Package completed		10/31/24								
Business Plan Completed		12/31/24								

BUDGET

Project Associated Expense	UND (NDIC)	UND (Federal)	Envergex (NDIC)	Envergex (Federal)	NDIC Total	Total Project
Personnel & Fringe	$144,477	$349,138	$167,397	$397,698	$311,874	$1,058,711
Operating	$14,271	$37,152	$20,900	$11,840	$35,171	$84,163
Equipment	$16,000	$95,146	$10,000		$26,000	$121,146
Indirect Costs	$75,337	$158,379	$51,070	$121,332	$126,407	$406,118
Total	$250,085	$639,816	$249,367	$530,870	$499,452	$1,670,138

NDIC funding will be matched at a 2.3 to 1 ratio using $1.2 million in federal funds. The federal dollars consist of ***80% of the scope of work*** for UND and Envergex LLC under the second phase of their cooperative agreement DE-AR0001314. NDIC funding adds new scope to the federal project with a focus on direct air capture. Failure to secure the $499,452 of NDIC funding will result in cancellation of the new DAC scope entirely. Budget justifications for UND and Envergex is provided in the appendix.

CONFIDENTIAL INFORMATION

Appendix A contains proprietary information regarding the proposed Flex-DAC™ process and the E-CACHYS™ sorbent.

PATENTS/RIGHTS TO TECHNICAL DATA

Existing Intellectual Property[xiii] developed under previous Department of Energy grants will be the basis for the development of the DAC-optimized sorbent technology. Any new intellectual property developed under the proposed project will be protected in accordance with relevant clauses.

STATE PROGRAMS AND INCENTIVES

NDIC projects:	Award Name:	Period	NDIC Amount
FY17-LXXXIII-210	Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks	10/1/2019 - 3/31/2022	$900,000
FY20-XC-222	Rare Earth Element Extraction and Concentration at Pilot	6/1/2021 - 11/30/2022	$286,234
R-046-056	Electrostatic Lubrication Filtration of Wind Turbine Oil	2/1/2021 - 6/30/2022	$151,494
FY21-XCIV-233	Electrostatic Filtration of Large Lubricant Reservoirs	2/1/2021 - 12/31/2022	$75,000.00
R-035-044	Preparation of Graphene-Modified $LiFePO_4$ Cathode for Li-ion Battery	3/1/2018 – 3/31/2020	$238,366

Renewable Energy Program

Request for Confidentiality

A person or entity may file a request with the Commission to have material(s) designated as confidential. By law, the request is confidential. The request for confidentiality should be strictly limited to information that meets the criteria to be identified as trade secrets or commercial, financial, or proprietary information. The Commission shall examine the request and determine whether the information meets the criteria. Until such time as the Commission meets and reviews the request for confidentiality, the portions of the application for which confidentiality is being requested shall be held, on a provisional basis, as confidential.

If the confidentiality request is denied, the Commission shall notify the requester and the requester may ask for the return of the information and the request within 10 days of the notice. If no return is sought, the information and request are public record.

Note: Information wished to be considered as confidential should be placed in separate appendices along with the confidentiality request. The appendices must be clearly labeled as confidential. If you plan to request confidentiality for **reports** if the proposal is successful, a request must still be provided.

Applicant: University of North Dakota
Application Title: Flexible Direct Air Capture System – Flex-DAC™

Please provide the following information. Use additional pages if more space is needed.

1. A general description of the nature of the information sought to be protected.

   Appendix A contains proprietary information regarding the CACHYS™ sorbent. The information presented as confidential consists of the technical details governing the current formulation, proposed modifications to make the sorbent technology suitable for direct air capture formulation and proposed equipment designs for the commercial system.
2. An explanation of why the information derives independent economic value, actual or potential, from not being generally known to other persons.

   The information provided in the confidential appendix A contains details on novel applications of the existing intellectual property that could result in new intellectual property. The small business partner, Envergex LLC core revenue source is derived from novel technology offerings and licenses. The applicant, University of North Dakota, seeks to develop new intellectual property that would advance its research goals.

3. An explanation of why the information is not readily ascertainable by proper means by other persons.

   Components of the proposed technology rely on existing intellectual property and unique knowledge on the subject matter by the project team. New components of the proposed technology rely on a novel combination of existing literature and methods developed by the team, to create a new and non-obvious technology/concept.

4. A general description of any person or entity that may obtain economic value from disclosure or use of the information, and how the person or entity may obtain this value.

   Any entity involved or planning to get involved with CO_2 capture technology deployment or development could potentially benefit from the confidential information presented.

5. A description of the efforts used to maintain the secrecy of the information.

   Currently, all parties involved in technology development are bound by non-disclosure agreements. Additionally, if project is awarded and development successful, we anticipate filing patent applications to protect developed intellectual property.

[signature]
Signature

Director | Institute for Energy Studies, University of North Dakota
Title

08/01/2022
Date

APPENDIX B: BIBLIOGRAPHY

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Envergex LLC
10 Podunk Road
Sturbridge, MA 01566

4200 James Ray Drive, Suite 301
Grand Forks, ND 58202

August 1, 2022

Dr. Daniel Laudal
Director | Institute for Energy Studies
University of North Dakota
2844 Campus Rd. Stop 8153
Grand Forks, ND 58202-8153

Re: Support of the proposal entitled "**Flexible Direct Air Capture System – Flex-DAC™"** submitted to the North Dakota Industrial Commissions Renewable Energy Council

Dear Dr. Laudal,

This letter confirms Envergex LLC's commitment to support your proposal efforts to evaluate the E-CACHYS™ sorbent-based capture technology, of which I am the inventor and rights holder, as a direct air capture (DAC) sorbent technology. Our preliminary evaluations of the sorbent's potential as a DAC sorbent have been very promising and by synergistically matching these efforts with our current efforts under DE-AR0001314 to develop a flexible E-CACHYS™ process, we could significantly advance the application to commercialization.

Envergex will provide support to the project to accomplish the following tasks outlined in the project proposal.

Task 1 – Model Development and NPV Optimization of the Flex-DAC™ Process: This task will focus on modelling activities to optimize the commercial design of the Flex-DAC™ process. Envergex will modify their existing NPV optimization model for the E-CACHYS™ process and adapt it to the Flex-DAC™ process. We will engage potential partners such as Steffes Corporation and their electro-thermal storage (ETS) system to facilitate integration into the model. We will work closely with UND personnel to develop pricing scenarios for our NPV optimization model using the GenX capacity expansion model.

Task 2 – Design and Construction of Pilot DAC Adsorber Module: This task will focus on the design and construction of a DAC adsorber for the E-CACHYS™ sorbent. Envergex will support UND with the manufacturing of the sorbent and sizing of the adsorber.

Task 3 – Pilot-Scale Testing of the DAC Adsorber: This task will focus on pilot-scale testing of the sorbents for direct air capture. Envergex will work with UND to incorporate analytical measurements into the test system for material performance assessments. Envergex will participate in the development of the test matrices and execution of the test plan for data collection. Data analysis will be performed by Envergex personnel. Envergex will provide guidance on results prioritization for subsequent tasks.

Task 4 – Commercial Process Design and Economic Evaluation: Envergex will work closely with UND in this task to develop a preliminary design package of the Flex-DAC™ process including developing engineering drawings, material selection and process conditions. With this information, Envergex will then develop a business plan and commercialization pathway for the Flex-DAC™ process.

The overall budget for Envergex for the proposed work is $249,367 and includes equipment, labor and travel for work execution on the project. The estimated period of performance is 24 months starting on or around January 1, 2023. A budget summary is attached. Envergex LLC will also provide as matching funds with the Department of Energy ARPA-E project (DE-AR0001314) Phase II funds in the amount of $1,170,686.

Envergex LLC is committed to the development, testing and commercialization of advanced energy and carbon capture technologies. The development of a low-cost technology for direct air capture of CO_2 is a critical need for the US in order to maintain a diverse fleet of electricity supply, and Envergex is pleased to collaborate with UND on this subject proposal. If there are any questions, please contact me at (508) 347-2933 or via email at srivats.srinivasachar@envergex.com.

Sincerely,

Srivats Srinivasachar
President
Envergex LLC

UNIVERSITY OF NORTH DAKOTA
Institute for Energy Studies

BUDGET JUSTIFICATION

Salaries and Fringe

Salary estimates are based on the scope of work. The labor rate used for specific personnel is based on their current salary rate. The annual personnel cost breakdown is listed in the table below.

Personnel	Role	Rate ($/hr)	Hours	Salary ($)	Fringe ($)	Total ($)
Junior Nasah	Project Manager	44.65	520	23,217	9,287	32,503
Daniel Laudal	Senior Management	91.59	180	16,486	6,924	23,410
Research Engineer	Research Assistant	36.71	870	31,939	14,053	45,992
Graduate Student	PhD Assistant	28.85	1300	37,500	188	37,688
Resource Manager	Administrative	22.61	180	4,070	814	6,887
TOTALS				**113,212**	**31,265**	**144,477**

Fringe has been estimated as 40% for the project manager, 42% for senior management, 44% for research engineer, 0.5% for graduate student, and 20% for resource manager. 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.

Materials & Supplies

These include items required for installation and operation of of the pilot test system such as gas bottles for analyzer calibration, tubing and fittings for connecting test equipment to analytical equipment. An itemized breakdown is presented in the Table below:

IES Supplies	Quantity	Unit Cost	Total	Justification
O2 gas bottle	5	$34	$170	Online estimate
N2 Gas bottle	5	$33	$165	"
CO2 gas bottle	5	$33	$165	"
Gas bottle rental, months	2	$500	$1,000	"
Plastic Tubing	500	$0.25	$125	"
Plastic fittings	100	$4.50	$450	"
Humidity Sensor	2	$200	$400	"
Total	**$2,475**			

Professional Fees and Services

These include licensing fees for the ASPEN Plus® simulation software and analytical usage costs for available equipment at the College of Engineering's Advanced Material Characterization Laboratory. The table below summarizes the various equipment, rates and estimated number of samples.

	Quantity	Cost	Total	Justification
Inductively-Coupled Plasma	50	$48	$2,400	Chemical composition of samples
Total Organic Carbon	50	$20	$1000	Carbon content of samples
ASPEN License renewal	2	$1000	$2000	Techno-economic process evaluation
Total			**$5,400**	

Equipment Costs

These include major pieces of equipment that will be integrated in the fabrication of the pilot system for testing. The table below identifies the equipment pieces.

	Quantity	Cost	Total	Justification
Air Blowers	2	2500	$5,000	Blowers to investigate capture performance against pressure drop
CO2 Analyzers	2	$5,550	$11,100	Measuring CO2 levels entering and exiting system
Swagelok stainless tubing	100	$2.50	$250	Fabrication of adsorber unit
swagelok stainless fittings	20	$25	$500	"
Mesh screens	8	$250	$2,000	"
NPT fittings	20	$40	$800	"
Thermocouples	10	$32.00	$320	"
Sheet metal	10	$166	$1,660	"
Flanges	2	$66	$132	"
Total			**$21,7620**	

Travel

Travel is estimated for two people to a technical conference to present the results of the proposed work.

# of People	# of Days	Flight	per diem	Hotel	Transportation	Total
1	3	$600	$50	$100	$35	1155
1	3	$600	$50	$100	$35	1155
Total						**$2,310**

Subaward / Subcontract

UND anticipates a sub-award to Envergex LLC of $249,909 with a breakdown provided in their letter of commitment.

Indirect Cost

The indirect cost rate included in this proposal is the federally approved rate for the University of North Dakota (41%). Indirect costs are calculated based on the Modified Total Direct Cost (MTDC), defined as the Total Direct costs of the project less individual items of equipment $5000 or greater, subcontracts in excess of the first $25,000 for each award, and graduate tuition waivers.

Budget Justification – Envergex LLC

Budget Period – 2 years

A. Project Leader, Dr. Srivats Srinivasachar will devote 350 hours of effort to the project for the Budget Period 1.

B. The salary labor rate for Dr. Srinivasachar is $ 110.10 per hour.

C. Engineers, working for Envergex, will staff the project in North Dakota. A total of 2100 hours will be devoted by the engineers.

D. The average salary rate for the Engineer/Scientist is at $33.35 per hour.

E. Fringe benefit rate of 54.26% of direct and indirect salaries and wages

F. Travel is estimated for 4 trips to University of North Dakota (Grand Forks, ND) from Sturbridge, MA at a rate $1475/trip for project execution related activities

G. Average Labor overhead is at 11.09% of direct salaries and wages and direct fringe

H. Average General & Administrative costs are 15.08% of (All Direct Costs (less subawards and Equipment) and Overhead)

I. Supplies (Sorbent Manufacturing) for project is estimated at $15,000 from prior vendor feedback

J. Equipment for pilot (sorbent support materials and construction) is estimated at $10,000

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
- Developed a business plan for coal and biomass to liquids venture
- 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). Developed a new product for controlling mercury emissions from coal-fired power plants.
- Principal Consulting Engineer, New Product Business Development (Oct. 1999 to March 2003)
- Multi-business product development for control of SO2 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)
    - Principal Research Scientist (1986-92) - Principal Investigator on a multi-million-dollar university-industry project

Patents (Selected) – 16 Patents

- U.S. Patent 9,121,606, "Method of manufacturing carbon-rich product and co-products"
- U.S. Patent 8,840,706, "Capture of carbon dioxide by hybrid sorption"
- U.S. Patent 7,981,835, "System and method for coproduction of activated carbon and steam/electricity"
- U.S. Patent 6,749,681, "Method of Producing Cement Clinker and Electricity"

Other Significant Products

- U.S. Patent 8,277,542, "Method of capturing mercury from flue gas"
- U.S. Patent 8,069,797, "Control of Mercury Emissions from Solid Fuel Combustion"
- U.S. Patent 6,089,171, "Minimum Recirculation Flame Control Pulverized Solid Fuel Nozzle Tip"
- U.S. Patent 6,089,023, "Steam Generator System Operation"
- Srinivasachar, Srivats, Nelson, Teagan, Mann, Michael, Dyrstad-Cincotta, Nicholas, and Laudal, Daniel. Supercritical Treatment Technology for Water Purification - Phase I STTR Final Technical Report. United States: N. p., 2019. Web

Publications

- Benson, S.A. and **Srinivasachar, S**. "Evaluation of CO_2 Capture from Existing Coal-fired Power Plants by Hybrid Sorption Using Solid Sorbents," 2014 NETL CO_2 Capture Technology Meeting July 29 – August 1, 2014, Pittsburgh, PA http://www.netl.doe.gov/events/conference-proceedings/2014/2014-netl-co2-capture-technology-meeting
- Benson, S.A., Crocker, C.R., Hanson, S.K., McIntyre, K.A., Just, B.J., Raymond, L.J., Pflughoeft-Hassett, D.F, **Srinivasachar, S.**, Barry, L.T. and Doeling, C.M., "JV Task 115-Activated Carbon Production from North Dakota Lignite – Phase IIA," Final Report, U.S. Department of Energy Cooperative Agreement No. DE-FC26-98FT40321, June 2008
- Tomomewo, O. S., Dyrstad-Cincotta, N., Mann, D., Ellafi, A., Alamooti, M., **Srinivasachar, S.**, & Nelson, T. (2020, September). Proposed Potential Mitigation of Wastewater Disposal through Treated Produced Water in Bakken Formation. In 54th US Rock Mechanics/Geomechanics Symposium. American Rock Mechanics Association.

Synergistic Activities

Expertise in energy and environmental engineering, power plant systems, and cross-industry product development. Led product/process development groups - ALSTOM Power Inc. (a global power generation company). Secured multiple patents and published over 60 technical papers.

JUNIOR N.D. NASAH
Institute for Energy Studies, University of North Dakota
Phone: (701) 777-4307; nasah.domkam@und.edu

Qualifications

2022	Ph.D. (Planned)	Chemical Engineering	University of North Dakota, USA.
2012	M.Sc.	Chemical Engineering	University of North Dakota, USA.
2007	B.Sc.	Chemistry	University of Buea, Cameroon.

Professional Experience

2019-Present: Major Projects Manager, IES, UND

Mr. Nasah's responsibilities include managing research projects specifically in the field of carbon dioxide mitigation including capture, storage and more efficient energy generation methods. His other key duties consist of identifying, developing and writing major funding proposals. Currently Mr. Nasah is a lead researcher investigating multiple sorbent technologies for capturing CO_2 from multiple sources and capturing fouling precursors that can be produced from high-alkali coals or biomass combustion.

2012-2018: Research Engineer, IES, UND.

Mr. Nasah's research focus included sampling methods to quantify ash size distribution during combustion processes, methods to separate char from oxygen carriers, coal gasification and advanced combustion methods. Mr. Nasah developed expertise in operating continuous emission monitoring systems, analytical methods such as total carbon and organic carbon measurements.

2013 – 2017: *Laboratory Instructor, Department of Petroleum Engineering, UND*

2010-2012: *Graduate Research Assistant, Department of Chemical Engineering, UND.*

Current Relevant Projects

Mitigation of Aerosol Impacts on Ash Deposition and Emissions from Coal Combustion, DE-FE0031756 (sub-awardee)	$5 million	2019
Cross-linked Micro-spherical Adsorbents from Lignite-derived Humic Acid for CO2 Capture, DE-FE0026825/S001343-USDOE (prime awardee)	$443,000	2020
Flexible Low Temperature CO2 Capture System, E-CACHYS™, DE-AR0001314 (sub-awardee)	$2 million	2020

Publications

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.

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, 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, 2015, 1100-1108.

Pei, P., Barse, K., Gil, A. J., **Nasah, J**. "Waste Heat Recovery in CO_2 Compression" International Journal of Greenhouse Gas Control. Volume 30, 2014, Pages 86-96.

Pei, P., Korom, S. F., Ling, K., **Nasah, J**. "Cost Comparison of Syngas Production from Natural Gas Conversion and Underground Coal Gasification" Mitigation and Adaptation Strategies for Global Change. 2014, 1-15.

Technical Reports

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.

Srinivasachar, S., **Nasah, J.**, Laudal, D. "Mitigation of Aerosol Emissions from Solvent-based Post-Combustion CO_2 Capture Systems." Final Technical Report, US Department of Energy Agreement No. DE-SC0015737, N. p. 2017.

Srinivasachar, S., Laudal, D., **Nasah, J.** "Method for Separation of Coal Conversion Products from Sorbents/Oxygen Carriers." Final Report, US Department of Energy Agreement No. DE-SC0013832. April 2016.

Synergistic Activities

Mr. Nasah's principal areas of expertise are carbon dioxide emission mitigation from fossil fuel generation sources. He has expertise on emissions characterization including fly ash from coal-fired power plants. Other areas of expertise include capture sorbent manufacturing such as activated-carbon based CO_2 sorbents and iron-based oxygen carriers.

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 2022

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 Cooperative
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. Young 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.

2006-2008 Field Engineer, Schlumberger Oilfield Services.
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).

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.

Synergistic Activities

Dr. Laudal’s principal areas of technical expertise are carbon capture, utilization and storage (CCUS), gas/solid contacting and reaction systems, solid sorbent technology development, and mineral processing. Of specific relevance to the proposed project is his experience in developing the Envergex/UND CACHYS™ technology platform for solid sorbent-based CO_2 capture. Dr. Laudal has a long history of managing and executing large multi-disciplinary and multi-organization R&D projects. He has been involved in a wide range of technology development, from early stages all the way through commercial projects.

AARON KOENIG

Research Engineer | Envergex LLC

Education and Training

University of North Dakota	Ph.D. Chemical Engineering	Expected 2022
University of North Dakota	M.S. Chemistry	2015
Saint John's University (MN)	B.S. Chemistry	2012

Research and Professional Experience

2018-Present Research Engineer, Envergex LLC

Served as the primary contributor to multiple past and ongoing modeling research projects. Possess expertise in chemical process simulations, computational flow dynamics modeling, and Python programming.

Modeling work includes design and economic assessment of power plant combustion and steam cycle process integration with CO_2 capture and energy storage technologies. Modeling was performed utilizing combinations of commercial, open-source, and customized python programming modeling platforms.

Modeling activities also includes time series optimizations of various chemical processes participating in energy arbitrage to evaluate the design and economic benefits of incorporating a storage aspect into the process.

This role also includes design and performance of laboratory and bench scale experiments responsibilities. Such work includes experiments related to the development of oxygen-carrier materials for chemical looping combustion applications.

2016-2017 Quality Control Technician, Cold Spring Brewing Company

Performed laboratory tests and record keeping of alcoholic beverage production processes.

2012-2015 Graduate Research/Teaching Assistant, University of North Dakota

Aided in research activities in the field of computational chemistry.

Synergistic Activities

Mr. Koenig is leading the modeling activities of a current project in which the CACHYS™ CO_2 capture process's operational flexibility and economic viability is being evaluated over a variety of potential future energy market scenarios. This project includes the development of a Python model to optimize the design and operations of a CACHYS™ process with sorbent storage that captures CO_2 from a gas turbine power plant which is subjected to highly variable electricity pricing. Additionally, Mr. Koenig is currently working to develop machine learning algorithms for the live prediction of electricity markets.

Industrial Commission

Tax Liability Statement

Applicant:
University of North Dakota

Application Title:
Flexible Direct Air Capture System - Flex-DAC

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

July 29, 2022
____
Date