UNIVERSITY OF UND NORTH DAKOTA

INSTITUTE FOR ENERGY STUDIES
COLLEGE OF ENGINEERING AND MINES
UPSON II ROOM 366
243 CENTENNIAL DRIVE – STOP 8153
GRAND FORKS, NORTH DAKOTA 58202-8153
PHONE (701) 777-3852 FAX (701) 777-4838

August 19th, 2022

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

Re: Proposal entitled "Modular Biomass Gasification for Co-Production of Hydrogen and Power"

Dear Ms. Fine:

The University of North Dakota Institute for Energy Studies is submitting a proposal in response to the Renewable Energy Program request for funding. In the proposed project, UND, Envergex LLC and Singularity Energy Technologiesare proposing to develop a modular, distributed biomass/solid waste to hydrogen, heat and power conversion system.

The team is requesting $500,000 from the North Dakota Industrial Commission for a 24-month project. The funds will be matched with $1.6 million from a newly awarded Department of Energy cooperative agreement, DE-FE0032182. The total value of the project is $2.12 million.

The $100 application fee has been submitted electronically using ACH. Two hard copies of the proposal will be sent using regular mail.

Do not hesitate to contact me with questions or requests for additional information.

Sincerely,

Daniel Laudal, Ph.D.
Director | Institute for Energy Studies
University of North Dakota
daniel.laudal@und.edu
701-777-5745

Karen Katrinak
Proposal Development Officer
Research & Sponsored Program Development
karen.katrinak@und.edu
701-777-2505

Renewable Energy Program

North Dakota Industrial Commission

Application

Project Title: Modular Biomass Gasification for Co-Production of Hydrogen and Power

Applicant: University of North Dakota

Principal Investigator: Junior Nasah

Date of Application: 8/19/2022

Amount of Request: $500,000

Total Amount of Proposed Project: $2,120,000

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 Rd Stop 8153 Grand Forks, ND 58202-8153

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ABSTRACT

Objective: The overall goal of the proposed work is to demonstrate a novel process-intensified and modular Combined Hydrogen, Heat and Power (CH^2P) production technology, targeting commercial scales of 5 – 10 MW_e equivalent. Our process technology integrates a novel adaptation of the steam-iron process to produce high purity hydrogen from gasification of biomass and biomass blends with a compression-ready carbon dioxide (CO_2) stream, enabling significant progress towards DOE's target of $1/kg cost of clean H_2.

Our process addresses the challenges to small-scale modular hydrogen production by: **i)** use of a novel iron-based material, referred to as the oxygen carrier material (OCM), with multi-functionality including syngas purification, flexible hydrogen production and carbon dioxide separation, **ii)** adopting a commercially available, low cost, modular, downdraft bed gasification system known as the Sandwich™ Gasifier, specifically designed for variable quality feed stocks at feed rates of 25-50 tonnes per day per module, and **iii)** tightly integrating the gasification process and synthesis gas conversion process to co-produce hydrogen heat and/or power.

Expected Results: Successful development for our technology will provide a pathway to low-cost hydrogen production at the small and distributed scale. The specific benefits to the State of North Dakota are significant as the process would use ND biomass (including agricultural waste residues) and municipal solid waste. At the scale we target, multiple commercial applications are feasible including power generation, local heating, hydrogen and potentially ammonia. These multiple options de-risk the technology and offer a unique value proposition for rural states like ND with significant agricultural activities. Large farms, rural cooperatives and small municipalities will be a key target market for the commercial system.

Duration: 24 months (suggested: 11/01/2022 – 10/31/2024)

Total Project Cost: $2,120,000. $500,000 requested from NDIC; $1,600,000 from U.S. DOE; $20,000 as in-kind cost share from Singularity Energy Technologies (SET).

Participants: University of North Dakota, Envergex LLC and Singularity Energy Technologies LLC

PROJECT DESCRIPTION

Objectives:

The overall goal of the proposed work is to demonstrate a novel process-intensified and modular Combined Hydrogen, Heat and Power (CH^2P) production technology that targets distributed, commercial scales of 5 – 10 MW_e equivalent. The CH2P process combines a modular, near-commercial gasifier technology – Sandwich™ gasifier, and a novel multi-functional oxygen carrier material (OCM) and syngas conversion process to produce high purity hydrogen. Specific technical objectives include:

- Demonstrate that our OCM is capable of producing high purity hydrogen and compression-ready CO_2 and is able to effectively manage syngas impurities. Our OCM will be developed using our team's patent-pending low-cost OCM manufacturing platform.
- Characterize the OCM cyclic stability, phase transformations and the inhibition potential of syngas impurities (sulfur, chloride and volatile organic compounds) on the OCM performance.
- Demonstrate and identify key operating conditions of the Sandwich™ gasifier operated in an oxygen-blown mode.
- Test a novel integrated laboratory unit that will **i)** convert a 5 lb/hr biomass feed to synthesis gas, and **ii)** convert the raw synthesis gas to high purity hydrogen using our OCM and our novel adaptation of the steam-iron process.
- Perform a techno-economic analysis (TEA) of the process, including evaluation of hydrogen purity, process heat and mass balances, and identify a pathway towards the DOE goal of \$1/kg of clean H_2.

Methodology:

Technology Description: Our proposed CH^2P process is a cyclic conversion process that will first produce synthesis gas from gasifying of biomass. Secondly, a series of fixed beds containing the OCM will be used to purify and oxidize the syngas to CO_2 and steam (OCM reduction step), and produce hydrogen and power from steam and air (OCM oxidation step). The major process steps are described further and presented in Figure 1.

Flexible Gasification: We will produce high BTU content synthesis gas via *modification of the patented*[1] *Sandwich™ Gasifier (SG) to facilitate oxygen-blown gasification*. The SG technology is an air-blown, downdraft-like, modular

[1] Patel, N. M. (2018). *U.S. Patent No. 10,011,792*. Washington, DC: U.S. Patent and Trademark Office.

gasification technology with module sizes ranging from 25-50 tonnes per day. Downdraft style gasification systems are characterized by very low tar concentrations, reducing the need for significant syngas clean up. The air-blown system is currently undergoing commercialization by targeting municipal solid waste (MSW). In this project, we will modify the design for *oxygen-blown gasification*, with the focus on biomass and MSW.

Novel Fixed Bed Steam-Iron Process: We propose a multi-functional, fixed bed system that will adopt current patent-pending and novel manufacturing methods and patentable OCM materials for conversion of syngas impurities, oxidation of syngas and production of hydrogen. This fixed bed system will cycle the inlet gas stream (and outlet gas stream) between the target beds. The syngas conversion step is exothermic and can produce high quality steam that is usable in the process to make hydrogen, or can be used to provide heat. Additional details on the multi-functional bed system are confidential and discussed further in the confidential appendix.

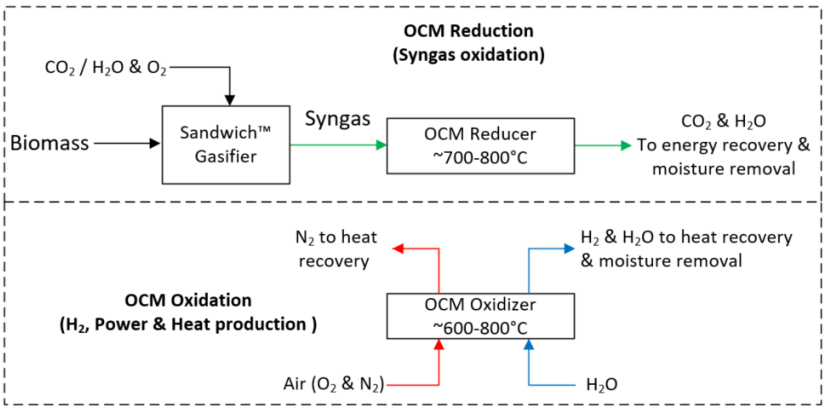


Figure 1. Schematic of proposed Combined Hydrogen, Heat and Power (CH^2P) process

Scope of Work: The project objective will be achieved through the following engineering activities: **i)** developing novel iron-based materials with multi-functionality OCM, **ii)** adopting a commercially available, low cost, modular, moving bed gasification system, **iii)** tightly integrating the gasification process and synthesis gas conversion process, and **iv)** performing a techno-economic assessment of the integrated process.

Task 1.0 – Project Management and Planning**:** This task will oversee project management activities including coordinating between project sponsors – the Department of Energy and the North Dakota Industrial Commission; and the project team consisting of University of North Dakota, Envergex LLC and Singularity Energy Technologies. As part of this task, a technology maturation plan detailing a pathway to commercialization of the technology will be developed and maintained throughout project execution.

Task 2.0 –Development and Evaluation of Novel Oxygen Carrier Materials (OCM): This task will initially focus on developing novel, multi-functional compositions of the OCMs targeting (a) syngas impurities (sulfur and organic compounds), and (b) syngas conversion to hydrogen. The primary parameters investigated will include composition, particle size of the raw materials, the final physical form of the OCM (structured bed or pellets), and curing method. A benchmark OCM already developed by the team will be adopted as the baseline formulation for developing the structured or pelletized OCM materials. This benchmark composition will serve as the basis for performance evaluation of the novel multi-functional OCMs. Next, prepared formulations will be screened by evaluating the chemical performance of the manufactured OCMs using UND's high temperature reactivity test system, Figure 2, and a thermogravimetric analyzer-differential scanning calorimeter (TGA-DSC). The multi-functional compositions will be evaluated against the benchmark composition. Key testing performance metrics will include conversion to hydrogen for various inlet syngas composition (varying ratios of carbon monoxide - CO, hydrogen - H_2, carbon dioxide - CO_2, and water - H_2O), fate of syngas impurities (sulfur as H_2S, volatile organic compounds - VOC), and structural / morphological changes of the OCM.

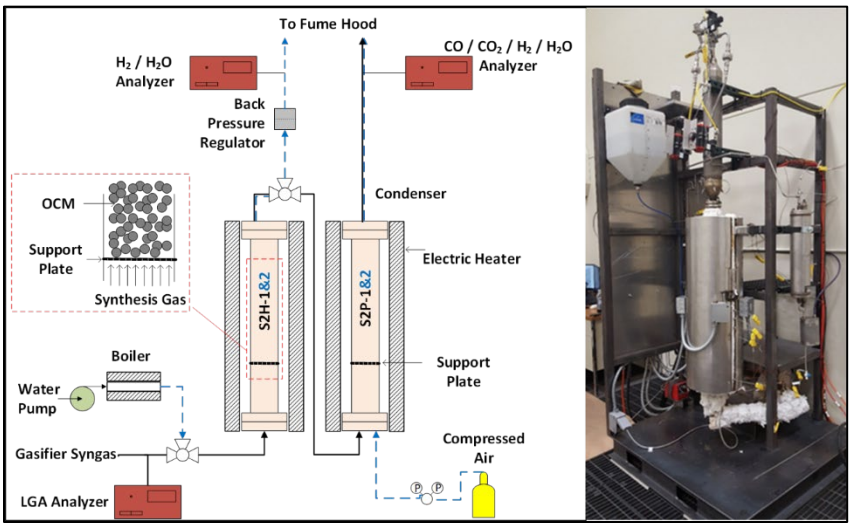


Figure 2. UND's proposed OCM attrition/reactivity test system.

Test parameters investigated will include **1)** operating temperatures, **2)** gas-solid ratios (bed loading) and **3)** syngas composition. Typical tests will involve multiple cycles of syngas conversion and OCM reactivation over 8 to 10-hour duration. Fresh and cycled OCMs will be characterized using scanning electron microscopy energy dispersive spectroscopy (SEM-EDS) to determine chemical/physical transformations, and assess morphological changes. X-Ray Diffraction spectroscopy (XRD) will be used to determine the formation, if any, of new crystalline compounds. Three formulations will be down-selected using results of these characterizations for further evaluation.

The long-term performance of the OCM (up to 1000 hours) will be evaluated using a synthetic composition of syngas that will include the effect of sulfur (as H_2S) and VOCs. Additionally, the task will investigate the effectiveness of OCM cleaning methods. This task will be critical for determining long term trends or transformations not observed over shorter test durations. Data from this test will determine OCM lifetime as a function of replacement or cleaning. SEM-EDS and XRD will be used to evaluate chemical and morphological changes after extended evaluation.

Task 3.0 – Laboratory Scale Evaluation of Oxygen-Blown Gasifier: Biomass and Municipal Solid Waste (MSW) feedstocks will be procured and characterized. Key characterization activities will include proximate and ultimate analysis, ash analysis, energy content, heat capacities (combusted feedstock residues), ash viscosity and slagging temperatures. Characterization results will be leveraged to identify optimal blend ratios of biomass and MSW that maximize synthesis gas quality. Finally, the procured biomass and MSW blend will be prepared (e.g. drying, torrefaction) for gasification testing.

UND's laboratory-scale Sandwich gasifier unit designed for feed rates of 5 lb/hr (under air gasification) will be modified to add oxidant feed ports and replace the natural gas burner with electric heaters. All other systems will be maintained. To identify optimal oxidant feed ports, a heat distribution model of the gasifier will be used to determine optimal operation conditions. The heat distribution model will be based on fuel characteristics and will be a function of fuel conversion, oxidant feed rates, bed temperatures and slagging potential.

Parametric testing of the biomass and biomass/MSW blends under oxygen-blown conditions will be performed. Key operating conditions investigated during gasification will include fuel type – biomass only and biomass blend; oxidant composition (non-Nitrogen diluent content), operating temperature, gasifier residence times and bed composition. During testing, the syngas composition will be analyzed to determine carbon monoxide, hydrogen, carbon dioxide, hydrocarbon content and impurities. Impurities including volatile organic compounds and sulfur compounds will be determined using established gasification monitoring methods such as the Environmental Protection Agency's Method 23 and Method 16. Fuel conversion to syngas determined from fuel feed rates and syngas composition and flowrate will be determined. Bed ash material will be recovered and characterized for elemental composition (fate of elements) using Inductively Coupled Plasma – Optical Emission Spectroscopy, X-Ray Fluorescence Spectroscopy and Scanning Electron Microscopy. Parametric testing will target short duration tests of 8 to 24 hours. Feedstock with optimal syngas

composition will be down-selected for further testing in Task 4.0.

Task 4.0 – Integrated Hydrogen Production: Production of the down-selected multi-functional OCMs developed in Task 2 will be scaled up to produce 1 to 10 kg of material. The OCM test bed will be manufactured as a fixed bed reactor for conversion of syngas to hydrogen including cleaning steps. The design will include external electric heaters for temperature control, multi-gas analyzers to measure syngas composition, steam generators and sorbent traps to determine impurity composition.

The OCM test bed will be installed on UND's Oxygen blown gasifier and operated as an integrated system. The biomass or biomass blend feedstock identified in Task 3 will be the fuel tested. Both the baseline and down-selected multi-functional OCMs will be evaluated. Key operating parameters investigated will include bed temperature (three levels), OCM regeneration and gas/solid contacting conditions. A comprehensive analytical campaign will be included, with focus on evaluating the extent of syngas conversion to hydrogen, pollutant emissions determined using established EPA Methods 16 and 23, hydrogen purity and OCM performance/stability. Post-test analytical methods will investigate OCM structure and morphology with a focus on impact of impurities on composition and structure.

Task 5.0 –Techno-Economic Analysis (TEA): In this task, an integrated heat and mass balance (HMB) based on the results of testing the down-selected multi-functional OCMs will be developed using the process evaluation software ASPEN Plus® for a facility equivalent to 5 to 10 MW_e power production. The TEA will be considered a Class IV – Study or Feasibility, according to AACE International, with costing accuracy in the range of approximately +/- 30%.

Anticipated Results

Project success will be measured by successful development of the CH^2P process, quantified by the successful production of high purity hydrogen using both baseline and novel OCM formulations. This success will require successful production of syngas during oxygen-blown gasification of biomass and successful elimination of any syngas impurities that would adversely impact the OCM and/or hydrogen.

Facilities

The proposed project will leverage the exceptional existing analytical and gasification/combustion and OCM testing equipment available at UND including the Advanced Materials Characterization Laboratory, and IES fabrication shop. We propose modifications to existing equipment at IES's laboratory as described below:

Sandwich™ Gasifier System: UND is home to a lab-scale air-blown SG system with propane fired heating (photo to right). The unit will be modified to incorporate electric heaters to monitor heat fluxes and facilitate remote control.

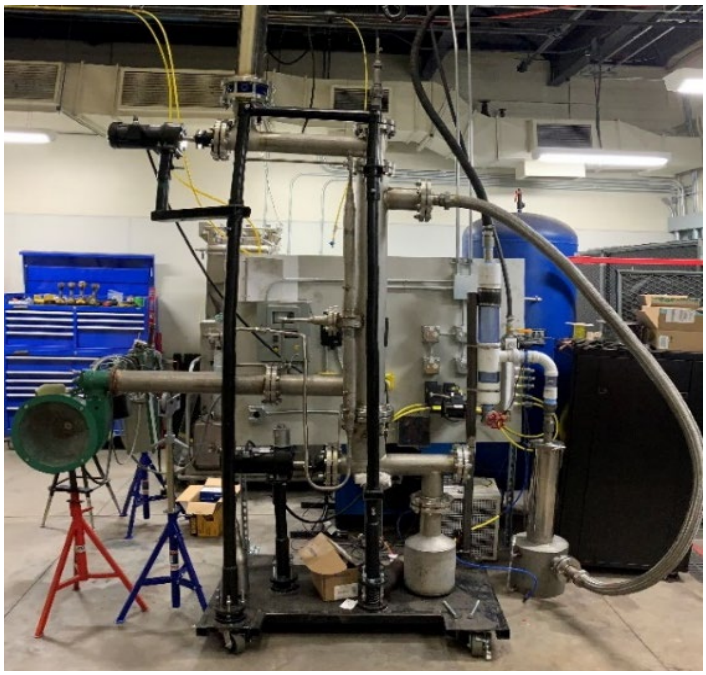


Figure 3. Image of UND's Bench Sandwich Gasifier

Attrition/Reactivity Evaluation and CH²P Unit: IES is home to two attrition reactivity units (Figure 2 previously) and proposes to modify one of the units to serve as the CH²P process (left schematic in Fig. 2). The modification will evaluate reduction (solid black lines in schematic) and oxidation (dashed blue lines) of OCM material.

Resources

Key equipment available at the AMCL will be critical for project success including:

FEI Quanta 650 FEG Scanning Electron Microscope (FE-SEM): This field emission SEM is capable of obtaining high-resolution data from almost any sample material. The instrument is operable in both high- and low-vacuum modes. The x-ray microanalysis system consists of an energy-dispersive x-ray detector (Bruker QUANTAX 200). The instrument can achieve 1–3 nm resolution.

Carbon Analyzer TOC SSM 5000A analyzer (Shimadzu, Japan): Total carbon (TC), inorganic carbon (IC), total organic carbon (TOC) analyses via Shimadzu TOC Analyzer and SSM-5000A Solid Sample Module in both aqueous and solid samples. The carbon content of effluents, ash and reduced OCM materials will be tested by this carbon analyzer.

Agilent 5110 Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES): The Agilent 5110 Synchronous Vertical Dual View (SVDV) ICP-OES features unique Dichroic Spectral Combiner (DSC) technology that enables synchronous radial and axial measurements. The typical Method Detection Limit (MDL) of most elements is ~1 ppb. It will be used to determine impurities on the OCM material after testing.

X-Ray Diffraction – Rigaku Smartlab: A fully automated XRD that utilizes cross-beam optics (CBO) to enable fast and

easy changing of the incident X-rays by substituting selection slits. The unit is equipped with a CCD camera for imaging of specific areas. It will be used to determine the crystalline phases of the non-stoichiometric OCM material.

Techniques to Be Used, Their Availability and Capability

OCM Manufacturing: The team has significant experience with OCM manufacturing including previous production of over 200 kg of the baseline OCM formulation for evaluation under a chemical looping combustion project funded by the DOE[2]. The patent-pending formulation method will be adopted to develop new OCM chemistries.

Chemistry and Thermodynamics: The OCM chemistry and thermodynamics is well understood by the project team and in literature, as it is based on the mature steam-iron process and gasification technology. The steam-iron process is a commercially mature process.[3] SET provides expertise on gasification of target fuels. The team will use thermodynamic modelling software (HSC Chemistry 9.0) to identify optimal operating schemes for the new OCM chemistries prior to evaluation during bench testing.

Bench Scale Testing: The team will leverage existing equipment at UND to develop bench units of the gasifier and CH^{2}P process. The team has been developing OCM under a just ended federal program[2] and with the lessons learned from that work, the team is well qualified to ensure success of the proposed bench scale system.

Process Modelling: The team will use ASPENPlus® for process modelling combined with heat-loss modelling to optimize the small-scale, distributed commercial systems and develop the techno-economic analysis of the process. Additionally, SET is in the process of commercializing their Sandwich™ gasifier and will provide key commercial data needed for process economics.

Environmental and Economic Impacts while Project is Underway

No environmental or economic impacts are anticipated during project execution.

Ultimate Technological and Economic Impacts

A key pathway towards decarbonization of the energy and transportation sectors is development of clean H_2 technologies with low to negative carbon intensity. The CH^{2}P process combines multiple innovative components that

[2] https://www.netl.doe.gov/project-information?k=FE0031534 Final Technical Report Submitted, pending publication

[3] Fan, Liang-Shih (2011). *Chemical Looping Systems for Fossil Energy*. John Wiley & Sons. p. 36. ISBN 1118063139

will advance the current state of the art for the steam-iron process, and expedite the commercial deployment. We identify multiple commercial applications that will de-risk deployment of the technology – power generation, heating, H_2 and potentially ammonia. All these potential by-products offer a unique value proposition for rural areas with significant agricultural activities. Large farms, rural cooperatives and small municipalities will be a key target market. In sum, our proposed technology and project will enable significant progress towards DOE's cost of H_2 target of $1/kg.

Why the Project is Needed

The need for the project is best described by the Department of Energy via the funding opportunity under which this project was awarded.[4] The FOA States: "Judicious use of biomass with incorporation of carbon capture and storage technologies is essential to enable net-zero life-cycle greenhouse gas emissions. The leveraging of gasification approaches offers opportunities to advance environmental justice because gasification technology can convert varied waste feedstock materials into clean energy with superior environmental performance, including the attainment of net zero greenhouse gas emissions." This project meets the target objectives by enabling the conversion of biomass, especially biomass waste with other waste sources to produce energy in an environmentally friendly method.

STANDARDS OF SUCCESS

The standards of success will include: **1)** Successful development of a process to make hydrogen at distributed scale using biomass and/or waste resources. **2)** Successful development of a manufacturing method and oxygen carrier material that can purify syngas from gasification processes and cyclically convert the syngas to hydrogen and/or heat and power. **3)** A techno-economic evaluation to determine the optimal size for commercial deployment of the process at a distributed scale. **4)** A pathway to commercialization of the technology in North Dakota.

BACKGROUND/QUALIFICIATIONS

UND: UND's Institute for Energy Studies (IES) is the prime applicant and will lead efforts regarding gasifier modification/testing, development of the CH^2P process and the TEA. IES' experience includes development and testing of OCM^2, gasification of non-coal fuels, hydrogen production from solid fuels[5], mitigation/capture of high temperature

[4] https://netl.doe.gov/node/10444

[5] https://www.netl.doe.gov/project-information?p=FE0032061

impurities using sorbent materials[6], and developing TEAs following the guidelines of the Association for the Advancement of Cost Engineering (AACE). The team led the DOE-funded $1.9 million chemical looping project (FE0031534) where the proposed novel OCM manufacturing method was developed, including two TEA's for the novel OCM manufacturing process and for a 580 MW power plant facility.

Envergex LLC: Envergex will be a sub-recipient and will lead efforts regarding manufacturing the OCM. They will assist with process design of the CH^2P process and TEA. They are the developer of the patent-pending manufacturing method proposed for development of the OCM under DOE project FE0031534. Envergex LLC has extensive experience with sorbent development and energy process development, with an ongoing $2 million award to develop a sorbent-based flexible carbon dioxide capture process using optimization modelling[7]. Envergex LLC also led development of the high temperature reactivity test system at IES (Fig. 1) that will be critical for evaluating the proposed OCM[8], collaborated with UND on OCM testing activities for development of Alstom's Calcium-based chemical looping technology and flue gas clean up[9], and has over 15 years in technology development activities with UND-IES.

Consultants: Singularities Energy Technologies (SET), holder of the Sandwich™ Gasifier patent, will serve as a project consultant to assist with modification of the SG laboratory scale gasification system at IES facilities for oxy-blown gasification. SET is a North Dakota-based small business committed to developing a cost-effective waste-to-energy conversion platform. SET is in the process of raising funding for a commercial-scale demonstration of their SG technology (with the base air-blown operation) and will provide key business data required for performing the TEA.

Key personnel in the project will include:

Mr. Junior Nasah: Mr. Nasah, Manager Major Projects at UND IES will be the project's Principal Investigator. Mr. Nasah has over ten years of research project development which includes 3 years of project management activities. Mr. Nasah's area of expertise includes carbon management including chemical looping development. He served as PI of

[6] https://www.netl.doe.gov/project-information?p=FE0031756

[7] https://arpa-e.energy.gov/technologies/projects/flexible-low-temperature-co2-capture-system-e-cachystm

[8] Srinivasachar, S. et al. Methodology for Attrition Evaluation of Oxygen Carriers in Chemical Looping Systems: Final Scientific/Technical Report - Phase II. United States.

[9] Braun, T. J et al. Frederic. Improvement of Alstom's Limestone-Based Chemical Looping Combustion Process for Higher Purity Flue Gas Production. United States. https://doi.org/10.2172/1440031

FE0031534[2] and oversaw the development of the OCM manufacturing method including scaled up production from 1 to 250 kg batch production.

Dr. Daniel Laudal: Dr. Laudal, Director of UND IES, will assist Mr. Nasah in the management of the project to ensure that resources, personnel and equipment are available for successful project execution. In addition to his management oversight role, Dr. Laudal has over 15 years' experience associated with management and execution of research programs related to fuel conversion processes and advanced power generation systems. Dr. Laudal has extensive experience in OCM and process development, with past work including OCM development and optimization and development of new process and reactor designs for chemical looping combustion. He led the bench-scale testing on a project partnering with GE/Alstom in development of their limestone-based CLC technology and an oxygen polishing system for the CLC reducer.

Dr. Srivats Srinivasachar: Dr. Srinivasachar, President of Envergex LLC, will be a Co-PI on the project and will work closely with Mr. Nasah to lead the technical aspects of the proposed scope of work and technology development. Dr. Srinivasachar previously worked at ALSTOM Power for 13 years in their coal and gas-fired power plant R&D group. Dr. Srinivasachar/Envergex LLC has collaborated with UND on multiple projects related to OCM development. Dr. Srinivasachar is the inventor of the CACHYS™ technology (US Patent 8,840,706) for CO_2 capture co-developed with UND, and Mer-Cure™ technology for mercury control.

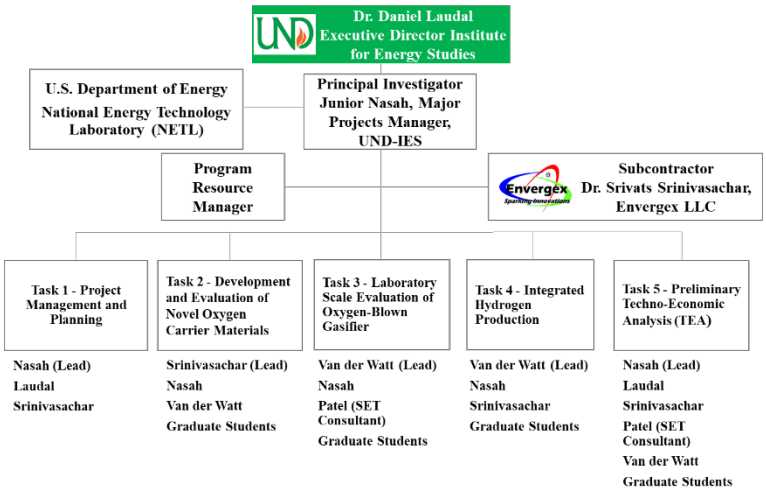
Dr. Johannes van der Watt: Research Engineer and Instructor, UND-IES, will focus on OCM evaluation and testing of the Sandwich™ Gasifier process. He brings over 5 years' experience in advanced coal combustion and gasification technologies, particularly in chemical looping combustion/gasification sorbent manufacturing and testing (DE-FE0031534[2] and DE-SC0011984[8]). He led the design and construction of UND's laboratory-scale SG equipment in collaboration with SET and has developed an ASPENPlus® gasification model of the SG process, and CFD model of OCM conversion. He will lead experimental activities of the project.

Dr. Nikhil Patel: President of SET and inventor of the Sandwich™ Gasifier, Dr. Patel has 25 years of research and technology development experience in the combustion and gasification of biomass, coal, and unconventional, difficult-to-burn liquid and solid industrial and municipal solid wastes. Dr. Patel has 15 years' experience at the Energy and Environmental Research Center (EERC) at UND where he focused on zero-effluent discharge gasification technologies

including the Sandwich™ Gasifier technology. Dr. Patel founded Singularity Energy Technologies, LLC in 2014 as a spin-off company of the EERC for commercializing Sandwich Gasification Technology. SET aims at using this technology as a core technology for waste conversion to electricity, liquids and other chemicals.

MANAGEMENT

Mr. Junior Nasah, PI, reports to Dr. Daniel Laudal, Director of UND IES, and will work closely with Dr. Laudal to ensure that resources, personnel and equipment are available to the project. A Resource Manager will be responsible for budget tracking and management and will work closely with Mr. Nasah and Dr. Laudal. Task leaders have been established for each of the project tasks. The figure above shows the project organization structure, which is designed on a task-by-task basis with Task Leaders and key personnel identified for each task.



TIMETABLE

		Start Date	End Date	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Task 1	Project Management and Planning											
1.1	Project Management Plan	11/1/22	10/31/24									
1.2	Technology Maturation Plan	12/1/22	10/1/24									
	Milestone 1.1 - PMP Updated	11/30/22										
	Milestone 1.2 - Preliminary TMP	1/31/23										
	Milestone 1.3 - Final TMP	10/1/24										
	Quarterly and Final Reports											
Task 2	Development & Evaluation of Novel Oxygen Carrier Materials											
2.1	Laboratory Scale OCM Manufacturing	12/1/22	10/2/23									
2.2	Characterization and Performance Testing	2/1/23	12/1/23									
2.3	OCM Lifetime Evaluation	1/2/24	8/1/24									
	Milestone 2.1 - Downselection of OCM	12/1/23										
	Deliverable A - OCM Development Report	1/1/24										
	Milestone 2.2 - 1000 hr cycle completed on downselect	1/29/24										
Task 3	Lab Scale Evaluation of Oxy-Blown Gasifier											
3.1	Feedstock Procurement & Characterization	1/2/23	3/31/23									
3.2	Heat Distribution Modelling and Equipment Upgrade	2/2/23	6/3/23									
3.3	Synthesis Gas Production	6/1/23	10/1/23									
	Milestone 3.1 - Synthesis Gas Characterization	11/15/23										
Task 4	Integrated Hydrogen Production											
4.1	Catalyst Manufacturing	10/1/23	1/2/24									
4.2	Hydrogen Reactor Fabrication	10/2/23	2/1/24									
4.3	Integrated Testing	2/1/24	9/1/24									
	Milestone 4.1 - Integrated Testing Completed	9/16/24										
Task 5	Preliminary Techno-Economic Analysis	11/15/23	10/31/24									
	Milestone 5.1 - Gasifier Heat Mass Balance	2/16/24										
	Milestone 5.2 - Integrated Heat Mass Balance	8/16/24										
	Deliverable B - Techno-Economic Analysis	10/31/24										

BUDGET

Project Expense	UND (NDIC)	UND (Federal)	Envergex (Federal)	SET (Federal)	NDIC Total	Total Project
Personnel & Fringe	$354,610	$459,379	$389,105	$50,000	$354,610	$1,253,094
Operating	$0	$169,809	$6,400	$0	$0	$176,209
Equipment	$0	$94,588		$0	$0	$94,588
Indirect Costs	$145,390	$246,280	$184,439	$0	$145,390	$576,109
In kind	$0	$0	$0	$20,000	$0	$20,000
Total	$500,000	$970,056	$579,944	$0	$500,000	$2,120,000

NDIC funding will be matched at a 3.2 to 1 ratio using $1.6 million in federal funds and $20,000 in private in-kind funds. The federal dollars consist of ***~75% of the scope of work*** for UND and Envergex LLC under the new award DE-FE0032182. NDIC funding serves as costshare for the bulk of the federal funding ($1.5 million). Failure to secure the $500,000 of NDIC funding will jeopardize the funding opportunity and stop work on the project until a new source of cost share can be secured and approved by the Department of Energy. Budget justifications for UND, sole recipient for NDIC funds is provided in the appendix.

CONFIDENTIAL INFORMATION

Appendix A contains proprietary information regarding the proposed CH^2P process.

PATENTS/RIGHTS TO TECHNICAL DATA

Intellectual Property developed under previous Department of Energy grants will be the basis for the development of the CH^2P 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: Modular Biomass Gasification for Co-Production of Hydrogen and Power

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 OCM formulation and CH^2P process. The information presented as confidential consists of the technical details governing the current formulation, proposed modifications to make the OCM technology suitable for flexible hydrogen production from gasification-derived syngas, operating philosophy of the CH^2P process 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's 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. The consultant on the project is currently commercializing technology systems related to the proposed process and is interested in licensing relevant IP developed during project execution.

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 hydrogen production and modular gasification 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

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

08/17/2022
Date

Appendix B – Letters of Commitment

Envergex LLC
10 Podunk Road
Sturbridge, MA 01566

March 28, 2022

Mr. Junior Nasah
Manager, Major Projects
Institute for Energy Studies
University of North Dakota
2844 Campus Rd Stop 8153
Grand Forks ND 58203

Re: Support of the proposal entitled "**Modular Biomass Gasification for Co-Production of Hydrogen and Power**" submitted in response to DE-FOA-0002400

Dear Mr. Nasah,

This letter confirms Envergex LLC's commitment to support your proposed efforts in response to DE-FOA-0002400. We believe that UND's proposed project to evaluate the chemistry, optimize the performance, and perform a preliminary process design and techno-economic analysis of an integrated modular hydrogen production process using biomass and MSW feed stocks, presents a strong approach to the development of a cost-effective method for CO_2-negative hydrogen and power production. This novel approach, developed through collaborative efforts between UND and Envergex LLC, and building on prior technology and projects on chemical looping, has the potential to achieve the goal of net negative carbon emissions for hydrogen and power.

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

Task 1 Project Management and Planning: The purpose of this task is coordination and planning of the project with the Office of Fossil Energy. Envergex will support UND to address all items related to monitoring and control of project scope, cost, and schedule. Envergex will support UND to update the project plan after initial negotiations and periodically as necessary. Envergex will provide input for quarterly technical reports, topical reports, participate in meetings and make presentations at contractor's conferences as required by DOE. Envergex will provide input to and collaborate with UND to develop and update the Technology Maturation Plan (TMP).

Task 2.0 – Development and Evaluation of Novel Oxygen Carrier Materials (OCM)
This task will focus on experimental activities for laboratory-scale OCM manufacturing. Existing and prior-developed techniques will be leveraged to manufacture multi-functional compositions of OCM for syngas conversion to hydrogen and targeting of syngas impurities. In a second sub-task the manufactured materials will be characterized for reactivity, conversion to H_2, performance over multiple cycles of oxidation and reduction. In a third sub-task, long-term performance over several hundred cycles will be evaluated using synthetic gas compositions. Envergex lead this task and direct the selection of the sorbent materials and participate in the formulation of several test

materials for evaluation. Envergex will also lead test plan development and execution of experimental tests, development/modification of test plans as required. Envergex engineers will conduct tests along with UND personnel on the TGA and other lab-scale equipment.

Task 4.0 – Integrated Hydrogen Production: This task will focus on scaled up OCM manufacturing. Down-selected OCMs from task 2 will be scaled to produce 1-10 kg material. Subsequent testing will be conducted both as configuration of a fixed bed reactor and structured bed reactor. In a subsequent sub-task, the catalyst test bed will be installed on the exit of an oxygen-blown gasifier and evaluated with syngas. A comprehensive test campaign will be adopted evaluating the extent of syngas conversion to hydrogen and catalyst fate in regards to syngas impurities. Envergex will lead the catalyst manufacturing effort and support UND in the testing activities.

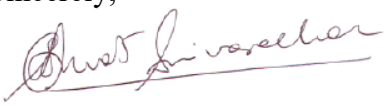
Task 5.0 – Preliminary Techno-Economic Analysis: Envergex will support UND in this task to develop of an initial process design using the best identified material(s) and process conditions. Envergex will support UND in performing energy and material balances, equipment sizing, equipment costing and operating cost definition. Envergex will support UND in preparing a Techno-Economic Evaluation report.

The overall budget for Envergex for the proposed work is $ 579,944 and includes labor and travel for work execution on the project. The estimated period of performance is 24 months starting on or about July 1, 2022. A budget summary is attached.

Envergex LLC is committed to the development, testing, and commercialization of advanced energy and environmental control technologies. The development of a low-cost technology for CO_2-negative hydrogen and power production is a critical need for the US, 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
E-mail: srivats.srinivasachar@envergex.com

Attachments: Budget Summary

SET SINGULARITY ENERGY TECHNOLOGIES, LLC
WASTE TO ENERGY

DR. NIKHIL PATEL
Founder & CEO

Suit 205, 4200 James Ray Dr.
Grand Forks, ND 58202
Cell Phone: 701-739-8720
https://www.singularet.com

March 18, 2022

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

Re: Support of the proposal entitled "Modular Biomass Gasification for Co-production of Hydrogen and Power" submitted in response to DE-FOA-0002400.

Dear Dr. Laudal:

This letter confirms the commitment of Singularity Energy Technology, LLC (SET), to support your proposed efforts in response to DE-FOA-0002400. We are confident that the approach proposed by the University of North Dakota (UND) to use our patented Sandwich gasifier as part of their process will make distributed hydrogen production more affordable and accessible to local and rural communities.

Backed by our experience in R&D, manufacturing, and operating Sandwich gasifier at all scales, SET will provide support to UND for executing project Task 3 and 5 of the proposal as a consultant and subject-matter-expert. In Task 3, SET will utilize its prior experience of gasifying biomass and municipal solid waste in the Sandwich gasifier to guide the team in selecting appropriate feedstocks and operating regimes to maximize the efficiency of the overall process. SET will interpret the results from this test campaign and support UND to assess the best commercial approaches through Techno-economic analysis as in Task 5. The efforts will contribute to expanding the Nation's hydrogen-based energy economy.

SET commits to consultancy support for the budgeted $50,000. The estimated project start date is September 2022.

SET is pleased to be a participant in the subject proposal and commits to cash-equivalent in-kind support of up to $20,000 that will include advisory services to the project team.

Please do not hesitate to contact me by phone or e-mail if you have any questions. I am looking forward to working with the University of North Dakota team.

Sincerely,

Nikhil Patel
President, SET, LLC

APPENDIX C – 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	Annual Salary ($)	Months	Salary ($)	Fringe ($)	Total ($)
Junior Nasah	Project Manager	95,096	4	31,699	12,120	43,818
Daniel Laudal	Senior Management	206,026	1	17,169	5,083	22,252
Research Engineer 1	Research Assistant	78,040	13	84,543	36,223	120,766
Research Engineer 2	Research Assistant	65,625	19.2	105,000	46,583	151,583
Resource Manager	Administrative	42,224	3.2	11,565	4,626	16,191
TOTALS				**249,976**	**104,635**	**354,610**

Fringe has been estimated as 38% for the project manager, 30% for senior management, 44% for research engineer, and 40% 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.

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. It is estimated at **$145,390**.

Appendix D – Resumes

Junior Nasah, Major Projects Manager, Institute for Energy Studies, University of North Dakota (UND)

Education and Training

University of North Dakota	Chemical Engineering	Ph.D. (Expected 2023)
University of North Dakota	Chemical Engineering	M.S. 2012
University of Buea, Cameroon	Chemistry	B.Sc. 2007

Research and Professional Experience

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

Mr. Nasah's responsibilities include identifying, developing and writing major funding proposals, managing research projects specifically in advanced power generation systems, energy, emissions control and mitigation. Currently Mr. Nasah is UND's lead on the 21st Century Power Plant project, developing the coal-fired plant of the future. He was the principal investigator of just ended chemical looping combustion project during which he oversaw the development of a novel oxygen carrier material. Other areas of interest include a CO_2 – capture ready advanced combustion system, and methods to mitigate aerosol formation during combustion of solid fuels.

2012-2018 Research Engineer, UND Institute for Energy Studies

Mr. Nasah's areas of research included investigating methods to improve advanced gas/solid contact systems in chemical looping combustion and co-developed technology for segregating char contaminants from oxygen carriers in chemical looping combustion. He is also co-inventor of a novel technology for extracting natural gas liquids from associated natural gas. Mr. Nasah's past work involves field-sampling trips at multiple power plants to measure and quantify the occurrence of fine particulate matter produced during varying combustion conditions. He has also been involved in investigating the feasibility of underground coal gasification for un-mineable lignite and investigating novel ways to curb mercury emissions from Taconite plants.

2009-2012 Research Assistant, UND Institute for Energy Studies

Researched and developed several sorbent-type technologies. Sorbents for the capture of mercury species from Taconite processing facilities; catalyst-type sorbents for the conversion of hydrocarbons to aromatic compounds.

2009 *Quality Assurance and Control Assistant, Fermentations, Cameroon*

Mr. Nasah performed quality assurance and control checks on the ethanol production line of the plant. Part of team in charge of verifying plant performance. Performed validation analyses on quality of products.

Select Publications

Nasah, J., Van der Watt, J.G., Mann, M., Musich, M., Koenig, A., Nelson, T. Srinivasachar, S., Benson, A., Fuka, M., and Benson, S. "*Low-Cost Recyclable Oxygen Carrier and Novel Process for Chemical Looping Combustion*." Final Technical Report. US Department of Energy Award Number: DE-FE0031534. Feb 2022

Nasah, J., Van der Watt, J.G., Musich, M., Koenig, A., Nelson, T. and Srinivasachar, S., 2022. Techno-Economic Analysis for a Low Cost and Recyclable Oxygen Carrier. *Clearwater Clean Energy Conference,* Clearwater, Fl.

Nasah, J., Jensen, B., Dyrstad-Cincotta, N., Gerber, J., Laudal, D., Mann, M. and Srinivasachar, S., 2019. Method for separation of coal conversion products from oxygen carriers. *International Journal of Greenhouse Gas Control*, 88, pp.361-370.

Srinivasachar, S., Nelson, T.R., **Nasah, J.**, Jensen, B.R. and Mann, M.D., 2019. Method for Separation of Coal Conversion Products from Sorbents/Oxygen Carriers *(No. DOE-ENVERGEX-SC0013832PhII). Envergex LLC, Sturbridge, MA (United States).*

Pei, P., Barse, K., Gil, A.J. and **Nasah, J.**, 2014. Waste heat recovery in CO2 compression. *International Journal of Greenhouse Gas Control*, 30, pp.86-96.

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

Pei, P., Korom, S.F., Ling, K. and **Nasah, J.**, 2016. Cost comparison of syngas production from natural gas conversion and underground coal gasification. *Mitigation and adaptation strategies for global change*, 21(4), pp.629-643.

Srinivasachar, S., Nelson, T., **Nasah, J.**, Laudal, D. and Benson, S.A., 2017. Mitigation of Aerosol Emissions from Solvent-based Post-Combustion CO2 Capture Systems: Final Scientific/Technical Report-Phase I STTR (No. DOE-ENVERGEX-SC0015737). Envergex LLC, Sturbridge, MA (United States).

Synergistic Activities

Principal areas of expertise are advanced combustion systems and emissions control for advanced and traditional fossil-fueled power generation. He is UND's lead for carbon management technologies and techno-economic analyses, with current projects including the 21st Century Power Plant funded by the Department of Energy, development of the E-CACHYS™ technology, a point-source technology funded by ARPA-E. Past work has included development of enabling technologies for fluidized-bed based systems. He has extensive experience in emissions monitoring at bench, pilot and field scale, and has performed multiple combustion-based testing for technology development or verification.

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

Education and Training

University of North Dakota	Master of Public Admin.	M.P.A. (Expected 2023)
University of North Dakota	Chemical Engineering	Ph.D. 2017
University of North Dakota	Chemical Engineering	B.S. 2006

Research and Professional Experience

2021-Present Director, UND Institute for Energy Studies

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. 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.

Select Publications

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.

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.

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.

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.

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.

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.

Synergistic Activities

Dr. Laudal's primary areas of technical expertise include advanced fuel conversion processes, carbon capture, utilization and storage, and high temperature redox systems. Of specific relevance to the proposed project is Dr. Laudal's experience with chemical looping combustion and gasification systems. Dr. Laudal was previously the IES lead researcher for CLC technologies and was the PI or co-PI on several successful DOE-funded efforts. While at Minnkota, Dr. Laudal was also previously the project manager for a $1B world-scale carbon capture and storage project, currently under development in North Dakota (Project Tundra). Dr. Laudal brings a unique mix of early-stage technology development, project management and commercial project development expertise. His role in the proposed project will be as project director, and he will oversee the execution of the project to ensure all resources are made available for successful completion.

Dr. Johannes George van der Watt, Research Engineer, Institute for Energy Studies University of North Dakota (UND)

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.

Synergistic Activities

Dr. Van der Watt has performed multiple combustion-based testing for technology development and/or verification, including oxygen carrier development, activated carbon manufacturing, and various sorbents testing. His principal areas of expertise are advanced combustion systems, computational fluid dynamics and process simulation. He has led the efforts to model UND-IES' novel chemical looping combustion technology on MFiX CFD software and brings both experimentalist and modeling capabilities to the project.

Dr. Srivats Srinivasachar, President, Envergex LLC

Education and Training

Boston University, School of Management	Master of Business Administration	M.B.A. 2004
Massachusetts Institute of Technology	Chemical Engineering	Sc.D. 1986
Indian Institute of Technology, India	Chemical Engineering	B. Tech. 1981

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. 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

Select 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.

Srinivasachar, S., 2012. *Sequestration Capture of CO_2 by Hybrid Sorption (CACHYS-TM) for Existing Coal-Fired Plants: STTR-Phase I Report* (No. DOE/SC/0004476-1). Envergex LLC, Sturbridge, MA (United States).

Srinivasachar, S., Nelson, T., Nasah, J., Laudal, D. and Benson, S.A., 2017. *Mitigation of Aerosol Emissions from Solvent-based Post-Combustion CO_2 Capture Systems: Final Scientific/Technical Report-Phase I STTR* (No. DOE-ENVERGEX-SC0015737). Envergex LLC, Sturbridge, MA (United States).

Senior, C.L., Bool III, L.E., **Srinivasachar, S.**, Pease, B.R. and Porle, K., 2000. Pilot scale study of trace element vaporization and condensation during combustion of a pulverized sub-bituminous coal. *Fuel Processing Technology*, *63*(2-3), pp.149-165.

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

Select Patents

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 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 6,749,681, "Method of Producing Cement Clinker and Electricity"

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"

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. Dr. Srinivasachar has developed engineered oxygen carriers for chemical looping combustion/gasification under cooperative agreement for DE-FE0031534. Dr. Srinivasachar is also the inventor of multiple activated carbon sorbent technologies which he scaled from pilot-scale to successful demonstration at three full-scale plants. About 250,000 lb of product have been supplied to six coal-fired units and tested to date.

Dr. Nikhil Patel, President, Singularity Energy Technologies, LLC (SET)

Education and Training

Indian Institute of Science, Bangalore	Aerospace Engineering	Ph.D., 2001
University of Baroda, Baroda	Mechanical Engineering	M.S. 1993
University of Baroda, Baroda	Mechanical Engineering	B.E., 1991

Research and Professional Experience

2020–Present: Co-founder & CEO, Dakota Green Power Co (DGP)

2014–Present: Founder & CEO, Singularity Energy Technologies, LLC (SET)

2005–Present: Adjunct Professor, Institute of Energy Studies (IES), Department of Chemical Engineering, UND.

2015–Present: Research Engineer Lead, Distributed Energy Technologies, EERC, UND.

2012–2015: Research Manager, EERC, UND.

2002–2012: Research Scientist, EERC, UND.

2002: Visiting Researcher, EERC, UND.

2000–2002: CSIR Research Associate, Indian Institute of Science, Bangalore, India.

1994–2001: Research Scholar, Indian Institute of Science, Aerospace Engineering Department, Bangalore, India.

1993–1994: Lecturer, University of Baroda, Baroda, India.

1991–1992: Research Assistant, University of Baroda, Baroda, India.

1989: Engineer Trainee, Mukund (Iron and Steel) Ltd., Bombay, India.

Patents

Patel, N.M., Singularity Energy Technologies LLC, 2022. *Sandwich gasification process for high-efficiency conversion of carbonaceous fuels to clean syngas with zero residual carbon discharge*. U.S. Patent 11,220,641.

Hutton, P. and **Patel, N**., Energy and Environmental Research Center Foundation (EERC Foundation), 2008. *Thermally stable cocurrent gasification system and associated methods*. U.S. Patent Application 12/035,331.

Benson, S., Stepan, D.J., Shockey, R., **Patel, N**., Swanson, M.L., Holmes, M.J., Solc, J. and Heide, C., Energy and Environmental Research Center Foundation (EERC Foundation), 2010. *Method and apparatus for improving water quality by means of gasification*. U.S. Patent Application 12/305,635.

Patel, N.M., 2020. *Sandwich gasification process for high-efficiency conversion of carbonaceous fuels to clean syngas with zero residual carbon discharge*. U.S. Patent Application 16/779,775.

Synergistic Activities

Dr. Patel has 25 years of research and technology development experience in the combustion and gasification of biomass, coal, and unconventional, difficult-to-burn liquid and solid industrial and municipal solid wastes. Dr. Patel currently leads efforts to commercialize mobile truck-mounted and stationary waste conversion technologies. These technologies utilize the patented Sandwich™ gasification process he invented while working at the Energy & Environmental Research Center (EERC). Dr. Patel joined EERC in 2002 and focused efforts on inventing, developing, and commercializing innovative gasification

technologies for distributed energy and Fischer–Tropsch (FT) liquid fuel production. As a research manager and research scientist at the EERC, he led the design, construction, and project management team responsible for implementing gasification-based demonstration and commercialization projects. Dr. Patel founded Singularity Energy Technologies, LLC, in 2014 to commercialize the Sandwich gasification technology. SET uses the Sandwich gasification technology it owns as a core technology for waste conversion to electricity and FT liquids and chemicals. In 2020 he co-founded and led as CEO of Dakota Green Power Co (DGP), an operating company for manufacturing and deploying SET's Sandwich

Industrial Commission

Tax Liability Statement

Applicant:
University of North Dakota

Application Title:

Modular Biomass Gasification for Co-Production of Hydrogen and Power

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 19, 2022

Date