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October 1, 2020

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

Dear Ms. Fine:

Subject: University of North Dakota proposal entitled "Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes"

Attached please find the subject proposal entitled "Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes" which is being submitted to the NDIC Lignite Research Program. The requested $75,000 funding will be used as a cost-share support to a DOE application (DE-FOA-00002185) submitted in July 2020. Using the funding provided by DOE and NDIC our battery research team can develop advanced lithium-ion battery anodes from lignite-derived carbon materials. Successful completion of this project will accelerate the commercialization of our business partner NACoal's existing project aimed at production of high-quality, lignite-derived pitch and synthetic graphite through opening a high-value lithium ion battery market.

We will pay the $100 application fee electronically.

If you have any questions, please contact me by telephone at (701) 777- 6350 or by e-mail at xiaodong.hou@und.edu.

Sincerely,

Xiaodong Hou
Principal Investigator
Institute for Energy Studies

UND is an equal opportunity/affirmative action institution

INSTITUTE FOR ENERGY STUDIES
THE UNIVERSITY OF NORTH DAKOTA

Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes

Submitted to:

Ms. Karlene Fine
North Dakota Industrial Commission Lignite Research Program
State Capitol
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Funding Requested: $75,000

Submitted by

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Oct 1, 2020

Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes

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Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes

1. ABSTRACT

The University of North Dakota (UND) is teaming up with Clean Republic LLC (CR), and The North American Coal Corporation (NACoal) to develop a high-value product from lignite-derived carbon materials. The overall goal of this proposed work is to develop and demonstrate an economic process for production of advanced silicon-carbon composite anode materials for lithium ion batteries (LIBs) using lignite-derived pitch and synthetic graphite as the main feedstock. The success of the proposed project will accelerate the commercialization of the team's existing technologies aimed at production of high-value LIBs materials from lignite coal. Development of battery materials manufacturing in the state utilizing North Dakota based feedstocks and processes allow for high potential of new industrial growth. The proposed project targets the key challenges facing the coal industry in a carbon-constrained world and is relevant to the DOE Office of Fossil Energy's mission and technology areas. The capability of supplying coal-based, high-value LIB anodes will not only increase the domestic and international marketability of U.S. coals but also enhance the competitivity of LIB manufacturers in the United States.

2. PROJECT SUMMARY

This project will involve collaboration between the University of North Dakota (UND) College of Engineering & Mines, Clean Republic LLC (CR), and The North American Coal Corporation (NACoal) to develop advanced lithium-ion battery (LIB) anodes from lignite-derived carbon materials. This collaborative work is based upon several previous and current projects performed at the Institute for Energy Studies (IES): coal tar pitch (CTP) and synthetic graphite (SG) produced by NACoal, a DOE UCFER (University Coalition for Fossil Energy Research) program sponsored project to develop silicon-based composite anodes for LIB from lignite, and a North Dakota Industrial Commission (NDIC)/CR (a LIB producer)-sponsored project to develop advanced LIB cathode materials from lignite.

The overall objectives of this proposed project are summarized below: 1) Prepare high-performance Si-C composite anode materials for LIBs using lignite-derived pitch and SG as the main feedstock; 2) Identify the optimal pitch and SG from a variety of sources produced by a sponsor for LIB anode applications; 3)

Develop a low-cost and scalable process to make porous and spherical Si-C composite anode materials; 4) Evaluate the battery performance of the new Si-C composite anodes and compare with a commercial anode as the benchmark; 5) Investigate the feasibility of making the new Si-C composite anodes at the bench-scale.

The expected technical and economic impacts are as follows: 1) The unique high-quality, lignite-derived pitch and synthetic graphite can serve as the versatile intermediate for high-value, carbon-based LIB anode materials such as Si–C composite anodes; 2) The proposed project will advance the current technology of preparing Si–C anode materials toward a low-cost and high-performance product; 3) The success of the proposed project will accelerate the commercialization of NACoal's existing project aimed at production of high-quality, lignite-derived pitch and SG through opening a high-value LIB market; 4) The capability of supplying coal-based, high-value LIB anodes will not only increase the domestic and international marketability of U.S. coals but also enhance the competency of LIB manufacturers in the United States.

The proposed project targets the key challenges facing the coal industry in a carbon-constrained world and is relevant to the Office of Fossil Energy's mission and technology areas. This project directly targets the overall goal of the current FOA (DE-FOA-0002185): to support the development of value-added products from coal, in particular AOI3 objectives, and seeks applications for technologies that use domestic coal as a manufacturing feedstock to produce solid carbon materials for high-value applications. This project leverages the unique technical expertise and interests from each institution and provides opportunities to enhance our ongoing collaborations.

3. PROJECT DESCRIPTION

3.1 Overall Project Goal

The overall goal of this proposed work is to develop and demonstrate an economic process for production of advanced LIB (lithium ion battery) anodes from lignite-derived carbon feedstock.

3.2 Project Objectives

Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes

The project aims to develop an advanced SiO/G/C (silicon/graphite/carbon) composite LIB anode materials from lignite-derived carbon feedstock. The specific objectives of this proposed project are summarized below: 1) prepare high-performance SiO/G/C composite anode materials for LIBs using lignite-derived pitch and SG as the main feedstock; 2) identify the optimal pitch and SG from a variety of sources produced by NACoal's proprietary technology for LIB anode applications; 3) develop an emulsification - spray drying process to make porous and spherical SiO/G/C composite anode materials; 4) evaluate the battery performance of the new SiO/G/C composite anodes, and compare with a commercial anode as the benchmark; and 5) investigate the feasibility of making the new SiO/G/C composite anodes at the pilot scale. The following sections provide a detailed description of the proposed technology to achieve these objectives

3.3 Scope of Work

The above objectives will be achieved through extensive laboratory testing aimed at developing new processes for Si-C composite anode preparation. A major effort will be made to optimize the emulsification–spray-drying and carbonization process as proposed. The existing equipment available at UND and collaborators will be operated in a batch manner. Lab-scale testing will be conducted at 1 gram per batch, and pilot-scale testing will be conducted at 1 kilogram per batch. The project has been divided into a series of tasks, with details below.

3.4 Tasks to be Performed

Task 1.0 – Project Management and Planning: This task shall include all work elements required to maintain and revise the Project Management Plan, the Technology Maturation Plan and the Data Management Plan and to manage and report on activities in accordance with each plan. It shall also include the activities to ensure coordination of the project with DOE NETL and other project participants. UND will be responsible for completion of this task, with input from CR and NACoal regarding project activities, scheduling, and information for project reports.

Subtask 1.1 – Project Management Plan. The Recipient shall manage and direct the project in accordance with a Project Management Plan to meet all technical, schedule and budget objectives and requirements.

The Recipient will coordinate activities in order to effectively accomplish the work. The Recipient will ensure that project plans, results, and decisions are appropriately documented and project reporting and briefing requirements are satisfied.

The Recipient shall update the Project Management Plan 30 days after award and as necessary throughout the project to accurately reflect the current status of the project. Examples of when it may be appropriate to update the Project Management Plan include: (a) project management policy and procedural changes; (b) changes to the technical, cost, and/or schedule baseline for the project; (c) significant changes in scope, methods, or approaches; or (d) as otherwise required to ensure that the plan is the appropriate governing document for the work required to accomplish the project objectives.

Management of project risks will occur in accordance with the risk management methodology delineated in the Project Management Plan in order to identify, assess, monitor and mitigate technical uncertainties as well as schedule, budgetary and environmental risks associated with all aspects of the project. The results and status of the risk management process will be presented during project reviews and in quarterly progress reports with emphasis placed on the medium- and high-risk items.

Subtask 1.2 – Technology Maturation Plan. The Recipient shall develop a Technology Maturation Plan (TMP) that describes the current technology readiness level (TRL) of the proposed technology/technologies, relates the proposed project work to maturation of the proposed technology, describes the expected TRL at the end of the project, and describes any known post-project research and development necessary to further mature the technology. The initial TMP is due 90 days after award and should be updated as needed throughout the project period of performance. A final TMP should be submitted within 90 days of completion of the project.

Task 2.0 – Analysis of Pitch and Synthetic Feedstock: The goal of this task is to select a few candidates, through analyzing and characterizing a variety of pitch and SG samples provided by a cosponsor, for anode preparation in Task 3.0. The main selection criteria include elemental (in particular, carbon) composition, ash content, softening point (for CTP), particle size, density, and graphitization (crystalline) degree (for SG). Elemental composition will be measured by an elemental (or carbon) analyzer and X-ray

Fluorescence Spectrometer (XRF). Ash content, softening point, and tap density will be tested following the relevant ASTM approaches D3174, D3461-18, and B527, respectively. Particle size will be characterized by SEM. Graphitization degree will be evaluated by XRD.

Task 3.0 – Development of SiO/G/C Composite Anodes

Subtask 3.1 Preparation of SiO/G/CTP Porous Microspheres. An optimal emulsification–spray-drying process to produce monodispersed porous microspheres using a commercial SiO and the CTP and SG feedstock selected in Task 3 will be developed building upon proof-of-concept validation previously illustrated. Key microsphere performance metrics: sphere size, sphere size distribution, and elemental distribution will be evaluated as a function of i) ratio of three precursors: SiO/G/CTP, ii) ratio of an emulsifier to precursor mixture, iii) type of emulsifiers, iv) solid content of emulsion (5%–20%), v) spray-drying inlet air temperature, and vi) nebulizer size of the spray dryer. A Taguchi orthogonal array built-in Minitab software will be used to design optimization experiments of these factors and investigate interactions between them. SEM-EDX will be utilized to characterize the sphere size, sphere size distribution, and SiO distribution in the microspheres.

Subtask 3.2 – Preparation of SiO/G/C Composite Anodes. This subtask will be aimed at optimizing the carbonization process to identify the best-performing SiO/G/C for LIB anodes. Key performance metrics of the SiO/G/C composite anode: spheritic morphology retention, carbonization degree (or residual carbon content), and porosity will be evaluated as a function of i) temperature (600°–1100°C), ii) time (1–12 h), iii) use of CTP for a second coating (0–20%), and iv)atmosphere (vacuum, N_2 or Ar). The experimental design method applied in Subtask 3.1 will be applied to this subtask. Besides the characterization methods applied in Task 2.0 and Subtask 3.1, carbonization degree will be estimated by the ratio of ordered/disordered carbon atoms through a Raman spectrometer, and the porosity will be tested by a BET surface area analyzer. In addition, building on the optimized carbonization procedure, a prelithiation process will be explored aimed at improving the ICE to >90%. The key challenge of prelithiation is to identify a low-cost and high-safety prelithiation agent (a lithium donor).

Subtask 3.3 Electrochemical Performance Testing. This subtask is to confirm that the synthesized SiO/G/C composite anodes have the expected electrochemical performance, including first-cycle reversible capacity, ICE, and long cycling life. The commercial anode S450-2A will be used to set benchmark battery performance. Electrochemical performance testing will be conducted on a Neware CT-3008 battery testing system (Neware Technology Limited) available at CR. CR2032 coin-type cells will be prepared with equipment currently available at CR. Current densities and specific capacities will be calculated based on the mass of the target compound of the electrode. Cycle life will be evaluated using a three-electrode system (ECC-REF, EL-Cell GmbH, Germany) for cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) tests available at UND.

Task 4.0 – Bench-Scale Test. This task is to evaluate the reproducibility of the optimized procedure at larger scale. The production scale of the SiO/G/C composite anode will be increased to 1 kilogram per batch. The lab-scale spray dryer can be directly applied to produce 1 kilogram-level microsphere intermediates, but the device for emulsification and the furnace for carbonization need be upgraded. All materials characterization and electrochemical performance testing methods applied in Tasks 2 and 3 will be applied to this task. Besides the CR2032 coin-type cells, full-size 18650 cylindrical cells using the optimal bench-scale sample will be fabricated. With the capacity several hundred times higher than a lab-made CR2032, 18650 cells are considered a popular size for a new battery material to be commercialized at a large scale.

Task 5.0 – Techno-Economic Analysis: This task aims to evaluate the technical and economic feasibility of the proposed technology and the market penetration possibilities. A TEA on the proposed process will be conducted after all process conditions/parameters are fully defined.

Task 6.0 – Final Report: A final project report will be compiled by UND, CR, NACoal and other project participants that provides detailed project results, discussion, and conclusions drawn from all work completed during the project. The final report will clearly specify the market potential of the proposed technology to produce the Si-C composite anode and will include a technical gap analysis.

3.5 Anticipated Results

The anticipated results of the proposed project are summarized as follows:

- Successful development and demonstration of a bench-scale process of producing LIB battery anode materials from lignite-derived carbon feedstock.
- Preliminary optimization for the process improvements and economics to maximize battery anode performance.
- Completion of a preliminary technical and economic feasibility study that will include detailed process flow diagrams, equipment specifications, mass and energy balances, and economic metric for the technology.
- This project will develop a high performance and economically viable process for generation of a high-value product from the vast lignite reserves in North Dakota. Successful demonstration will develop new avenues for increased lignite use in non-power generation sectors, permitting suitable product diversification.

3.6 Facilities and Resources

The facilities and equipment which will be available to the proposed project include:

Battery Assembly and Test Center, co-owned by UND and Clean Republic LLC. It has the capability to fabricate and test a verity of batteries from small size CR2032 coin-type cells, to full size 18650/26650 cylindric cells, and up to 48V battery packs. The cylindric cell fabrication facility consists of a set of machines for electrode coating, rolling press, vacuum drying, slitting, ultrasonic spot welding, winding, grooving and sealing. It houses a Neware BTS-3000n Battery Analyzer for coin-type cell, BTS 4000 Battery analyzer for cylindric cells, a HYNN-BP600A battery testing system, and a Gamry electrochemical workstation for large cylindric cells with the capabilities including charge/discharge characteristic test, capacity test, cycle life test, Cyclic Voltammetry (CV). Electrochemical Impedance Spectroscopy (EIS) analysis, and battery standard dynamic test.

Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes

Materials Characterization Lab (UND), the MCL was established to support UND research and educational activities, to support industry research and sample analysis needs, and to serve as a regional satellite lab. The laboratory is supported by experienced technicians and analytical chemists and has a vast array of analytical equipment and capabilities, including field-emission scanning microscope (FE-SEM) FEG 650 (FEI, USA); x-ray power diffraction (XRD) Smartlab (Rigaku, Japan); Zetasizer nano ZS90 (Malvern Instruments Ltd, UK); Thermo Scientifics' Nicolet NXR 9650 FT-Raman spectrometer; x-ray fluorescence spectrometer Supermini 200 (Rigaku, Japan); Thermogravimetric analyzer SDT-Q600(TA, USA); computer-controlled scanning electron microscope S3400 (Hitachi, Japan) with EDS (IXRF, USA);. The MCL will be used to examine the crystal purity, chemical composition, morphology and particle-size distribution of the Si-C composite anode materials as well as the lignite-derived pitch and synthetic graphite feedstock.

Institute for Energy Studies Lab, UND College of Engineering and Mines. This lab is equipped to perform chemical synthesis and processing steps and have a bench-size spray dryer (TP-S15, China), a pilot-scale jet mill (JSDL-Q-3, China); an atmosphere-controlled glove box (MBraun LABstar MB) for battery construction, and an atmosphere-controlled TFM2 2-Zone tube furnace (Across International, USA) and a bench-scale muffle furnace (KJ-a1200-27L, China) for carbonization steps.

Environmental Analytical Research Laboratory (EARL), UND College of Engineering and Mines. The equipment available to the proposed project include a lab muffle furnace with atmosphere control; carbon analyzer TOC SSM 5000A analyzer (Shimadzu, Japan), and Inductively coupled plasma optical emission spectroscope ICP-OES 5510 (Agilent, USA).

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

Other Resources: UND has fully equipped laboratories and larger bench and pilot-scale demonstration areas. Wet chemistry laboratories will be utilized in the proposed work to conduct some of the characterization work in Task 2, 3 and 4. UND also has a fully-equipped mechanical and electrical fabrication shop, with a full list of capabilities that include welding and machining as well as mechanical and electrical installation services. The shop is staffed by experienced personnel with the training and availability to perform the necessary work as requested. UND's office areas are equipped with all of the necessary software and computing requirements to complete the scope of work.

3.7 Environmental and Economic Impacts during Project

The environmental impacts resulting from performance of the proposed work are negligible. Waste streams produced as a part of testing will be disposed of via the existing waste disposal mechanisms available at UND, and any hazardous waste (if produced) will be handled according to UND regulations. Economic impacts include employment opportunities for UND research staff, students and support staff. This project will train the next generation of engineers/scientists that will benefit the North Dakota labor force.

3.8 Technical and Economic Impacts of Proposed Technology

Our project uses domestic U.S. low-rank lignite coals to produce a high-value product through a novel process. We believe this project will advance the technology of utilizing low-rank coal methods that maximize the coal value and significantly reduce environmental impacts. Primary outcomes are the high-value composite Si-C anode materials for LIBs and associated production processes. The proposed project will have the following impacts: 1) the unique high-quality, lignite-derived pitch can serve as the versatile intermediate for high-value, carbon-based anode materials such as silicon/graphite composite anodes; 2) the proposed project will advance the current technology of preparing silicon/graphite anode materials toward a low-cost and high-performance product; 3) the success of the proposed project will accelerate commercialization of NACoal's existing project aimed at production of high-quality, lignite-derived pitch and SG through opening a high-value LIB market; and 4) the capability of supplying coal-based, high-value

LIB anodes will not only increase the domestic and international marketability of U.S. coals but also enhance the competency of LIB manufacturers in the United States.

4. STANDARDS OF SUCCESS

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

- Successful development and demonstration of a process for economic production of high performance and low-cost battery anode materials.
- Evaluation of the battery anode material development pathways from lignite-derived tar and graphite feedstock, with materials tested to ensure high-quality (>20% improvement over current use materials) and low cost (>30% price reduction) battery anode materials.
- Development of a commercialization strategy, including a fully functional economic and financial model for evaluation of economic viability and commercial prospects.

5. BACKGROUND INFORMATION

UND has demonstrated the ability from previous projects to cost-effectively generate anode material products from North Dakota coals, including data below, showing promise for an economical and market-disruptive process.

5.1 Definition of the Research Problem/Opportunity

Coal has long been a reliable baseload energy source for the United States, but environmental and market forces have reduced coal production for power generation. This transition is forcing states like North Dakota, the host of the world's largest lignite deposit, to seek alternative opportunities to sustain coal-dependent economic development. Fortunately, a series of recent studies performed at UND have demonstrated that the unique properties of low-rank coals provide an opportunity to produce high-value products such as anode materials for LIBs.

5.2 Background

Graphite is the state-of-the-art anode for LIBs, but its poor low temperature performance, rate capability, and limited theoretical capacity (372 mAh/g) has motivated the development of next-generation anodes. . Alloy-forming materials such as silicon are among the most promising alternative to graphite because of theoretical specific capacities as high as 4200 mAh/g. However, a Si anode has a severe drawback: huge volume change (400%) during charging/discharging, leading to unsatisfactory overall battery performance such as low initial coulombic efficiency (ICE), large irreversible capacity C_{irre}, and very poor cycle life (**Table 1**).[1] The most effective solutions to those problems include designing effective morphologies (e.g., porous structure), reducing the particle size to nanoscale, and fabricating conductive carbon composites/coatings.[2]

Table 1. Commercial Anode Materials for LIBs.

Materials type	Anode materials	C_{theo} mAh/g	Ø 1st %	Lithiation V	Pressing density	Cycle life	Rate Capability	Cost	Common Issues	Market share %
Insertion	Natural graphite	340-370	90~93	0.2	1.6~1.85	>1000	Fair	*	Poor low temperature performance	25
	Artificial graphite	310-370	90~96	0.2	1.5~1.8	>1500	Good	**	Poor low temperature performance	65
	MCMB	280-340	90~94	0.2	1.5~1.7	>1000	Very good	***	Low specific capacity	3
	Hard carbons	250-600	80-85	0.52	1.3~1.5	>1000	Very good	***	High C_{irre}, immature technology	1
	Soft carbons	250-1000	80-85	0.52	1.3~1.5	>1000	Very good	***		1
	CNTs	1116	30~60	>0.5	–	<100	Poor	*****	High C_{irre}, high voltage hysteresis, poor cycle life	N/A*
	Graphene	1157	30-60	>0.5	–	<50	Poor	*****		
	$LiTi_4O_5$	175	98~99	1.55	1.8~2.3	>30000	Excellent	***	Very low energy density	4
Alloying	Si/SiO	1600~4200	~60	0.3~0.5	0.9~1.6	<300	Poor	****	Huge volume expansion	<1
	Sn/SnO_2	790~993	~60	0.4~0.69	–	<200	Poor	****	Huge volume expansion	N/A*

C_{theo} = theoretical capacity, C_{irre} = irreversible capacity, Ø 1st = first cycle efficiency, MCMB = Mesophase Carbon Micro Beads, and CNTs = carbon nanotubes. "N/A*" means not commercialized as a pure anode. *The market share data were reported in 2017, since then Si-based anodes have experienced tremendous growth.[3]

5.3 State of the Problem

In the race of advancing Si-based anode materials toward ultimate replacement of graphite, the Si–C composite anode at low-level commercialization is the front runner. Si–C anodes under industrial development usually composite a Si source (e.g., Nano-Si) with a large amount of (>70% in mass) commercial graphite for practical use.[2, 4] In spite of the significant progress, Si–C anodes prepared by this approach still have some technical drawbacks, such as low ICE and cycling performance. Besides, a key barrier that prohibits its full commercialization is the high cost, mainly due to the use of expensive nano-Si and commercial graphite as well as the complicated production process. From the perspective of lowing the cost of raw materials, as an abundant and cheap carbon source, coal or coal by-products have a great potential to enter the value chain of the LIB anode industry, as carbon-based materials are not only dominating the current anode market but also continue to play critical roles in the next-generation anodes such as Si–C anodes, as shown in **Table 1**. Technically, coal and coal by-products have been extensively studied as the feedstock for anode materials such as SG, turbostratic carbons, and nanostructured carbon materials.[5-8] Our recent research also found that lignite coal is an excellent graphene precursor for high-performance electrode materials for LIBs.[9-10] Therefore, development of a Si–C anode using low-cost raw materials such as coal and by-products as feedstock, integrating innovative production technologies synergistically to design effective morphologies and hierarchical micro-/nanostructures to overcome the technical drawbacks, could be an effective approach to develop low-cost and high-performance alternative anode materials for LIBs for the replacement of graphite

5.4 Proposed Technology

This section is hold confidential and included in the appendix for evaluation purpose only.

5.5 Scientific and Technical Basis

5.5.1. Preliminary Laboratory-Scale Data

The proof-of-concept has been validated in a low-fidelity experiment. SiO/G/C composite anode was synthesized via the proposed procedure illustrated in **Figure 1** using unpurified CTP (ash content 3.75%) and commercial SG (no grinding and size classification). The SEM images in **Figure 2a)** clearly demonstrate: 1) SiO, synthetic graphite and pitch form one type of composite particles with no heterogeneous agglomerates and single component-rich particles observed during spray drying and after carbonization, and 2) SiO particles were evenly distributed on the surface of synthetic graphite particles with pitch as the binder (**Figure 2b**). In **2c)** the first-cycle reversible specific capacity 543 mAh/g is about our target value (540 mAh/g) for a final product, and the ICE is 85%, close to the objective value 90%, and the capacity is not fading for 30 cycles (the test is ongoing).Overall, the electrochemical performance of the synthesized Si/G/C is satisfactory for an unoptimized procedure.

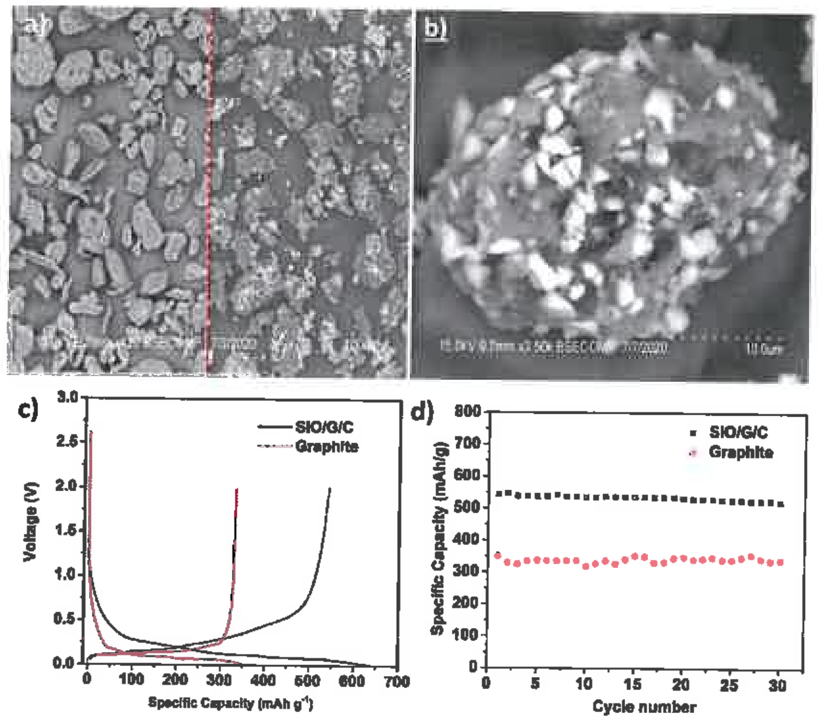

Figure 2. SEM images of commercial synthetic graphite (a, left), SiO/G/C (a, right) and a 10X image (b); specific capacity and columbic efficiency (c), and rate capability of the SiO/G/C composite anodes.

Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes

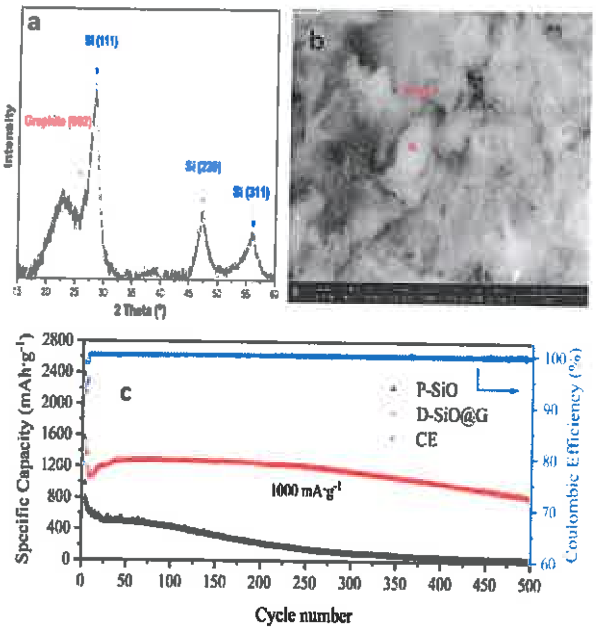

Figure 3. XRD profile (a), SEM image (b), specific capacity and columbic efficiency (c), and rate capability of SiO/G anodes.

The proposed emulsification-spray drying technology has also been proven in our previous project aimed at synthesizing a SiO/graphene composite anode using lignite-derived humic acid (the major organic matters of coals) as the graphene precursor. The SiO will be in-situ converted to Si particles via the disproportionation of SiO: $SiO \rightarrow Si + SiO_2$, simultaneously the humic acid will be converted to a graphene matrix to coat Si/SiO_2 composites under the reducing atmosphere. The XRD characteristic peaks of crystalline silicon (111), (220), and (311), and graphite (002) in **Figure 3a)** confirms the co-occurrence of the disproportion reaction of SiO: $SiO \rightarrow Si + SiO_2$ and the conversion of lignite-derived humic acid to graphene. The SEM image **3b)** clearly shows the SiO particles embedded in a network of wrinkled graphene sheets. In **3c)** the first-cycle reversible specific capacity 1600 mAh/g, and ICE close to 78.5%, and the capacity retention is 80% at 500th cycles.

Compared with 80% of SiO (high capacity but low cycling life) by weight used in the previous project, a lower percentage of SiO (~20%) used in the proposed composite anodes will result in a lower specific capacity but higher ICE and cycling life. Therefore, we strongly believe our proposed technology will produce a composited anode with well-balanced technical performance, and the performance objectives set in Section 5.7 have a low risk of failure.

5.5.2. Literature Review on Si-C Anode Materials

5.5.2.1. Silicon Source

Si-based materials are the most promising anodes for next-generation LIBs to replace the SOTA anode graphite, because of its high capacity, abundant sources, and being environmentally friendly. However, the large volume change that causes poor cycling performance is a major technical challenge to overcome before their practical application. SiO/C, Si-M alloy and Nano-Si–C are the most studied Si-based anode materials that attracted much industrial attention. The three anodes use different strategies, in particular, selection of different Si sources, to overcome the large volume change issue with silicon: SiO takes

Table 2. Comparison of the Most-Studied Three Types of Si-Anode Materials

Anode	Industrial Attention	Advantages	Drawbacks	Possible Solutions
SiO	Shin-Etsu Chemical, Sumitomo Titanium Corp, Samsung SDI, LG Chem and BTR	Excellent cycle life High specific capacity >1200 mAh/g	ICE <80%	Carbon coating prelithiation
Si-M	3M	Good cycle life Medium specific capacity >1000 mAh/g	Hard to control the microstructure High fabrication cost	Process optimization and automation
Nano-Si/C	Samsung SDI, LG Chem and BTR	Acceptable cycle life Very high specific capacity >2000 mAh/g	High cost of Nano-Si ICE <80% Low pressing density	Composite with graphite (>70%)

advantage of the twice as strong bonds of Si–O over Si–Si and the presence of Li_2O and Li-silicate (by-products produced during the first charging cycle) as a buffer zone, Si-M fabricates amorphous materials that retain homogeneous expansion and contraction, while Nano-Si/C adopts nanosized silicon (<150 nm) that prevent pulverization of particles. The current SOTA of the three Si anodes has been reviewed recently.[2] **Table 2** summarizes the main advantages, disadvantages, and possible solutions. In short, Nano-Si–C attracts the most attention because of its potential high energy density, but the cost of nano-sized Si is high, and the energy density is significantly compromised by the upper limit of Si (<30%) added into the composite anodes. Si-M draws less attention, mainly because of the complexity of controlling the amorphous microstructure and high fabrication cost. In contrast, SiO has a higher technology maturity and better performance-price balance than its two counterparts. Relatively low ICE is another technical drawback for Si-based anode materials; carbon coating of SiO is widely adopted as a low-cost approach to improve the ICE to acceptable levels (~80%) for practical application. A breakthrough in high-safety and low-cost pre-lithiation strategy aimed to increase ICE to >90% may realize the full commercialization of the SiO–C anode.

5.5.2.2. Carbon Source

Almost all the carbon materials listed in **Table 1,** including ordered carbon (graphite), disordered (amorphous) carbon, and nano-structured carbon, have been used to prepare Si-C composite anodes. In general, graphite anodes have excellent cycling performance and high ICE but limited specific capacity and poor rate capability; disordered and nano-structured carbon-based anodes have increased capacities but increased irreversible capacities (i.e., low ICE) and poor cycling performance. In addition, benefiting from mature technology and mass production, graphite has more favorable price advantages over disordered and nano-structured carbon.[1] From the perspective of technology readiness level, in the short term, graphite will be the dominant carbon source for the Si–C composite anode. Artificial (synthetic) graphite is taking over natural graphite because of the limited geological sources of the latter. Commercial artificial graphite is mostly made from petroleum-derived needle coke, but the dramatically growing demand for furnace electrodes and LIBs is tightening the needle coke market. That brings tremendous opportunities to a very few companies worldwide, such as two Japanese companies Nippon Steel Chemical & Materials and Mitsubishi Chemical Corporation, producing coal-derived needle coke.[18] On the other hand, compared with numerous reports on preparing coal-derived pure-carbon anodes for LIBs,[5-8] only a few have prepared Si–C composite anodes using coal as a feedstock.[8, 19-20] Therefore, our proposed Si–C composite anodes using coal-derived SG and pitch as feedstock will not only be of a potential technical breakthrough in LIB industry but will also have great market advantages over those Si–C anodes under development using petroleum feedstock.

5.5.2.3. Control of Particle Morphology

Porous and spheritic anode materials have many desirable properties, such as high specific capacity and good rate capability because of their structure characteristics, including 1) short Li diffusion paths; 2) tunable porosity and high surface area to facilitate rapid charge transfer and minimize polarization effects; and 3) tunable microstructure, crystallinity, morphology, and composition for high specific capacities.[21] In morphology, our porous and spheritic SiO/G/C anodes assemble the spheritic MCMB (see **Table 1**), the commercial anode with the best rate capability. Besides, our SiO/G/C anodes have one additional advantage: higher capacity because of the addition of SiO. Unfortunately, conventional technologies heavily based on mechanical blending approaches such as ball milling can only produce nonporous and irregularly shaped Si-C particles, while our emulsification–spray-drying technology has the potential of producing a porous and spherical anode in continuous production mode.

5.6 Anticipated Technical and Economic Benefits over Current State-of-the-Art

This section is hold confidential and included in the appendix for evaluation purpose only.

5.7 Economic Discussion

5.7.1. Estimated Cost and Projected Selling Price

Table 3. Estimated Cost Structure of Si-C Composite Anodes with 80% Carbon

Cost Breakdown	*$/ton*[b]	*$/Our SiO/G/C Anode*	*$/Commercial Nano Si–C Anode*	*$/Commercial SiO–C Anode*
Micro-Sized SiO	20,000	4000		4000
Nano-Si	200,000		40,000	
Commercial Petroleum SG	10,000		7000	7000
Lignite-Derived SG	5000	3500		
Binder (CTP)	4000	400	400	400
Total Raw Materials Cost		7900	47,400	11,400
Production Cost[c]		25%	30%	30%
Labor Cost[c]		10%	10%	10%
Overhead[c]		5%	5%	5%
Total Cost		11,060	71,100	16,530
Market Price		20,000(Projected)	NA[d]	20,000
Profit		$8940		$3470
Profit Rate		81%		21%

[a] Assume all the anodes have identical starting materials: Si/graphite/binder = 20/70/10.
[b] The market prices are heavily quality-dependent; median prices of the high-quality products were used.
[c] Production cost, labor, and overhead are estimated by the actual percentage in current battery anode materials industry.
[d] This product is not commercially available at a large scale.

A more accurate TEA (techno-economic analysis) will be performed in the scope of work after all of the proposed processes has been optimized. **Table 3** provides a simplified estimate on the base case economic metrics of the proposed technology by producing 1 ton of our SiO/G/C composite anode, compared with two similar products. Although a greater level of detail is needed to determine the extract net profit per ton of SiO/G/C anode, our estimated profit rate of the commercial anode is in the reasonable range of 20%~30%, according to a recent market investigation report.[3] Apparently, given the same selling price, our anode product has a substantially higher profit rate than the commercial products because of significantly lower raw materials: nano-Si is over ten times more expensive than micro-sized SiO, and lignite-derived synthetical graphite can reduce the cost by 50% over commercial petroleum-based SG.

In addition, the production cost of our technology is expected to be lower than the conventional ball-milling-based technology: 1) our emulsification–spray-drying process is much faster and simpler than the ball-milling-based technology as it avoids some aggregate-breaking steps and 2) our process can be in continuous production mode. Therefore, it is safe to claim our proposed technology integrates low-cost, lignite-derived SG and CTP as well as inexpensive SiO as feedstock with a continuous and high-throughput spray-drying production process, providing tremendous economic advantages over competing similar products based on petroleum-derived graphite technologies and ball-milling-based production processes.

5.7.2. Anticipated Technical and Economic Benefits over Current Technologies

The detailed technical and economic benefits of our proposed technology over current technologies have been discussed in previous sections and are summarized as follows:

Lignite-Derived Carbon Materials for Lithium-Ion Battery Anodes

- Our emulsification–spray-drying technology can produce highly desired porous and spherical anode particles and also allows for better homogeneity of the composite materials that avoids the aggregate issue of conventional ball-milling-based technologies.
- Use of micro-sized SiO particles can avoid a series of technical challenges associated with nano-Si nanomaterials and reduce cost of silicon raw materials dramatically.
- Use of lignite-derived CTP and SG by our own business partner has significant economic advantages over the commercial petroleum-derived SG. In addition, our continuous and high-throughput spray-drying technology can also reduce production cost substantially.

Table 4. Main Technical and Economic Performance Target of the Proposed SiO/G/C Composite Anode

Performance Attribute	Performance Requirement	Reference Materials (S450-2A)
Specific Capacity (mAh/g)	540	450
ICE	>90	90
Cycling Life (with 80% of capacity retention)	500	300
Pressing Density (g/cm³)	1.7	1.65–1.75
Cost ($/ton)	11,060	16,530

5.7.3. Technical and Economic Performance Targets Required for Commercialization

The ultimate outcome is a market-ready Si–C anode for LIBs; therefore, the main technical attributes, including specific capacity, ICE, cycling life, and pressing density, must be well balanced with a competitive price. A commercial Si-C anode (S450-2A)[4] from the world's leading anode manufacturer (BTR) will be used as a reference to set benchmark battery performance. Overall, our product will reduce cost by about 30% but increase the specific capacity by 20% and cycling life by 60% (**Table 4**).

5.7.4. How the Technology Can Improve the Value Chain for Coal Production

Since the proposed technology uses lignite-derived pitch and SG as the feedstock to make a composite anode material for LIBs, it requires interface/integration between the mines, pitch and SG producers, and LIB manufacturers (end user). Our team includes all three members in the value chain: NACoal, operating surface coal mines under long-term contracts with power generation companies and activated carbon producers, is committed to providing pitch and SG through its proprietary technology. CR provides the facility for evaluation and potential production of anode materials. CR also has strong motivation for its current anode materials used in its LIB battery packs with the proposed one, provided the proposed technology is successfully commercialized.

5.7.5. Discussion of Product Market Potential

As the most promising power systems and energy storage devices of all the renewable energy technologies, the market size of LIBs has skyrocketed, promoted by rapidly increasing demands of a broad application from electric vehicles (EVs); consumer electronics such as cell phones, cameras, and laptops; and grid-level energy storage. The global demand and production capacity of electrode materials for LIBs were forecasted at a compound annual growth rate (CAGR) of 11.6%~12.5% by multiple leading advisory institutes worldwide in 2016,[22-23] which was dramatically underestimated in contrast to the actual CAGR >40% from 2017 to 2020. In 2020, the global market size for LIB anode materials is about 400,000 tons, >90% of which is still graphite (natural graphite and SG) and <5% Si-anode. However, the global market size of Si–C anode alone will grow to 500,000 tons at

a CAGR of 137% at least until 2025[24]; a main reason for that is the skyrocketing delivery of Tesla Mode 3 EV that has completely used the Si–C anode to replace conventional graphite. The global market potential of the solid products is listed in **Table 5**. The market volume size and market value by 2025 are based on

the predicted trend by recent market reports.[3, 24] The predicted global market value of the Si–C anode is $10 billion by 2025, a 50% by value and about 1/3 by market volume size of the total anode. Provided the carbon component of SG and Si-C anodes was 100% from coal, total coal utilization would be 3.5 million tons per year.

Table 5. Market Potential of the Anodes for LIBs by 2025

Solid Products	Market Volume (kilo-ton)	Annual Growth (%)	Market Value ($Billion)	Coal Utilized (million tons)
Anodes	1500	40	20	3.5
SG	650	20	6.5	2
Si–C Anodes	500	130	10	1.5

6. QUALIFICATIONS

UND Key Personnel: Dr. Xiaodong Hou, PI, Research Assistant Professor, is a material chemist at UND IES with over 15 years' experience in synthesis and characterization of advanced functional materials. He has over 30 peer-reviewed publications in the field of chemistry materials and holds five patents. He has been directing the multiple projects directly related to develop advanced electrode materials for LIBs. One of the technologies aimed to develop coal-derived carbon materials for composite electrode materials for LIBs has finished its pilot-scale test and is in the process of commercialization by CR.

Dr. Michael Mann, PD, Chester Fritz Distinguished Professor of Chemical Engineering, and Executive Director of IES, has been working in the energy field since 1981. He has over 215 publications and over 35 years of continuous funding covering a wide range of conventional and renewable energy technologies.

Dr. Robert Ilango: Postdoctoral Research Fellow at UND IES with over 8 years research experience in design and characterization of advanced electrode materials battery applications. He has over 15 peer-reviewed publications and two patents on Li-ion battery electrode materials. Currently, he is focusing on the preparation and characterization of porous-Si/Graphene composite for high-performance Li-ion batteries.

Brittany Rew: is an Engineer at UND IES who has been involved in previous and current projects related to the development of coal-derived carbon materials for LIBs. She has experience with bench-scale and pilot-scale testing of relevant technologies. Her work on previous projects has included involvement in the development of a techno-economic assessment of a novel process based on research completed at UND IES.

Shuai Xu: is a Ph.D. graduate of UND IES, focusing on advanced LIB anode research. He has over seven years' experience in development of lithium-ion battery electrode materials, in particular SiO/C anode. He has led a pilot-scale project to produce high-performance pitch/SiO composite anode via spray-drying technology.

CR Key Personnel: Dr. Yong Hou, cofounder and VP for Research at CR has 20+ years of experience in the lithium battery industry and has developed 14^+ cells and battery pack products that are successfully marketed. He has been concentrating on the development of electrode material since 2014, and CR is in the process of commercializing a technology spin-off from collaboration with UND IES. To facilitate the collaboration with UND, Yong also works at IES as a part-time senior material research engineer. He is leading several other projects related to energy storage application of LIBs.

NACoal Key Personnel: Dennis R. James, Director of New Technology, will serve as a pro bono consultant. He has more than 40 years of coal industry experience focusing on geology and geochemistry, with involvement in exploration, development, operations and reclamation of coal mines. Utilization of coal is also a primary focus area as it relates to identifying and solving coal quality related issues at existing plants (gasification and conventional). Interface with and coordinate various company interactions with industrial and academic research and development groups.

7. VALUE TO NORTH DAKOTA

North Dakota produces over 30 million tons of lignite annually. The state's economy is heavily invested in the production and use of lignite. Successful completion of the proposed project will open new high value commercial opportunities for lignite use. New industries will be realized if successful commercialization of the technology is achieved, providing new opportunities for high-paying jobs and new tax revenues for the State. Development of battery materials manufacturing in the state utilizing North Dakota based feedstocks and processes allow for high potential of new industrial growth.

8. MANAGEMENT

Figure 4 shows the organizational chart for the project. The core team assembled to perform the proposed work includes UND's IES, NACoal, CR, and the North Dakota Lignite Energy Council (LEC). The team brings together the expertise required to develop a novel process that can produce high-value composite anodes for LIBs from lignite coals. The project has been organized by task, with task leaders/team members responsible for completion of each task. Cost management will be coordinated by the Administrative Resource Manager who will be responsible for tracking all costs for each of the project tasks.

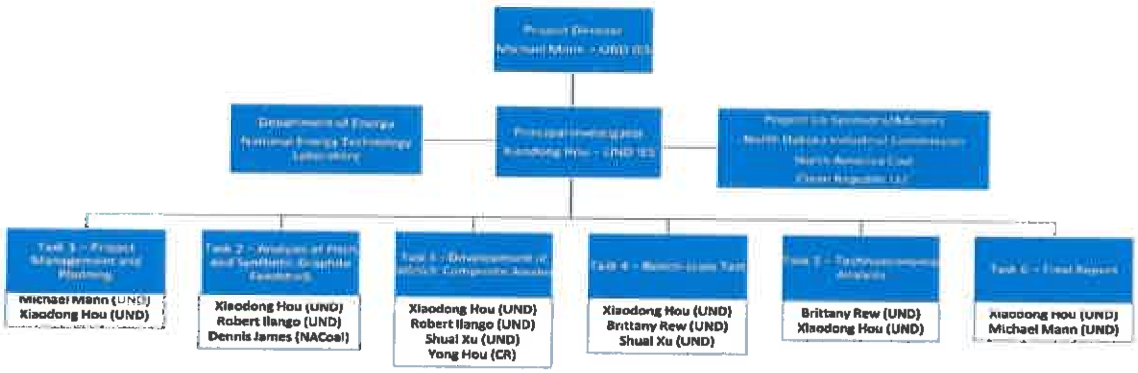

Figure 4. Project organization

Dr. Xiaodong Hou will be the PI, with the assistance of the PD Dr. Michael Mann. Dr. Hou will be responsible for managing resources and schedule, and coordinate meetings with all the project participants/sponsors. He will also be responsible for coordination of all projects within the UND IES and will work with the project team to ensure that all personnel, equipment and other resources are available to efficiently conduct the project.

Project meetings and conference calls will be held, at least, on a bi-weekly basis to conduct project activities, review project timelines, upcoming milestones/deliverables, costs and challenges associated with the completion of the project tasks. Microsoft Project management tools will be utilized. Project review meetings with sponsors will also be held on a quarterly basis to ensure communication and discussion of accomplishments, plans and management of project risks.

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

9. TIMETABLE

The proposed project timeline is 24 months, with an estimated start date of Jan 1st, 2021. The project Gantt chart is displayed in **Figure 5**. Major milestones and planned completion dates are provided in **Table 5.**

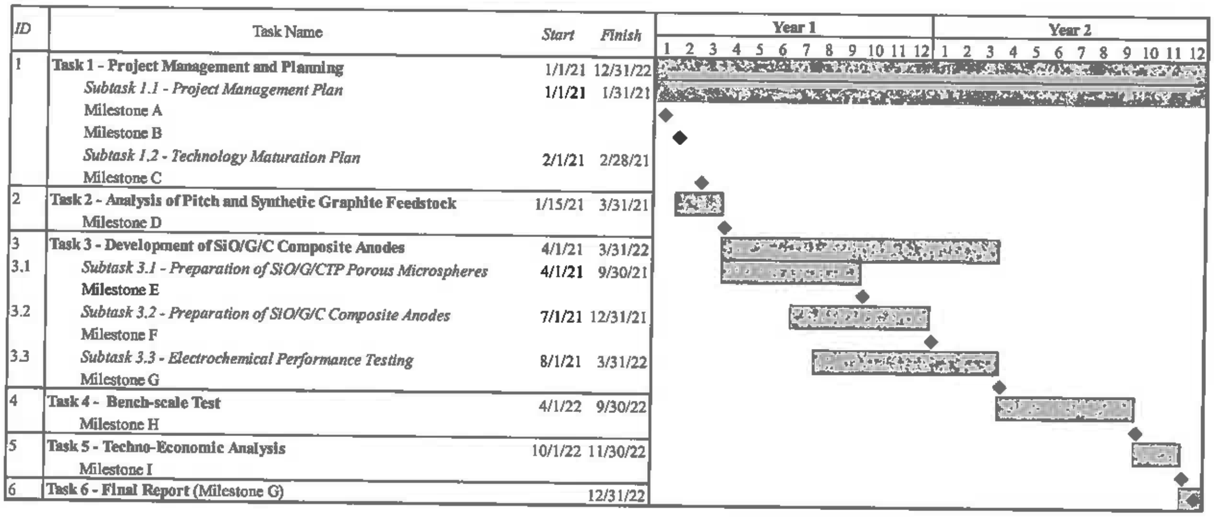

Figure 5. Project Gantt chart.

Table 5. Project Milestones Log

Budget Period	ID	Task Number	Description	Planned Completion Date	Actual Completion Date	Verification Method
1	A	1	Update project management plan	1/15/21		PMP file
1	B	1	Kickoff meeting	1/31/21		Presentation file
1	C	1	Update technology maturation plan	2/28/21		TMP file
1	D	2	Determine the lignite-derived pitch and synthetic graphite candidates	3/31/21		Task report
1	E	3.1	Determine the optimal synthetic procedure for SiO/G/CTP microspheres	9/30/21		Quarterly report
1	F	3.2	Determine the optimal synthetic procedure for SiO/G/C composite anodes	12/31/21		Quarterly report
2	G	3.3	Complete the battery performance evaluation	3/31/22		Task report
2	H	4	Complete the bench-scale test	9/30/22		Task report
2	I	5	Complete the TEA	11/30/22		Task report
2	G	6	Final technical report	12/31/22		Final report

10. BUDGET

The following table gives the summary of the total project budget and the requested funding for each of the cost share partners and the Department of Energy. To simplify the subcontracting and equipment purchases, those costs have been assigned solely to the Department of Energy and only personnel/benefits have been assigned to the cash cost share partners.

Budget Category	Project Total	DOE	NDIC	NACoal	Clean Republic
Personnel	$277,224	$197,422	$43,329	$29,187	$7,286
Fringe Benefits	$65,187	$52,232	$9,863	$2,728	$364
Travel	$10,001	$10,001			
Major Equipment	$35,000	$35,000			
Materials and Supplies	$42,000	$42,000			
Fees	$64,864	$28,000			$36,863
Total direct charges	$494,276	$364,656	$53,192	$31,915	$44,513
F&A	$173,189	$135,158	$21,809	$13,085	$3,137
Total Cost	**$667,465**	**$499,815**	**$75,000.00**	**$45,000.00**	**$47,650.00**
Percent of Total	100.00%	74.70%	11.30%	6.80%	7.20%

Personnel

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

Personnel	Role	Months	Hours	Salary	Fringe	Labor cost
Xiaodong Hou	PI	7.0	1211	50558	17695	68253
Michael Mann	PD	2	347	33143	11600	44743
Yong Hou	Key Personnel	2	347	12032	4211	16243
Robert Ilango	Key personnel	6	1040	22550	7893	30443
Brittany Rew	Key personnel	4.5	780	26167	9158	35325
Sara Ogundonlani	Administrative	3	520	15465	5413	20878
Shuai Xu	Research Assistant	24	2080	33517	3352	36869
Graduate 2	Research Assistant	24	2080	33517	3352	36869
Undergraduate 1	Research Assistant	24	2080	25138	1257	26394
Undergraduate 2	Research Assistant	24	2080	25138	1257	26394

Total	277224	$65,187	$342,411

Fringe Benefits

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

Travel

A breakdown of travel is presented in the table below and includes travel required by DOE to review meetings and sampling field trips. Costs have been estimated based on available airfare and lodging rates, conference fees, standard per diems and other UND travel policy. Estimates are broken down as follows:

Purpose of Travel	Depart From	Destination	No. of Days	No. of Travelers	Lodging per Traveler	Flight per Traveler	Vehicle per Traveler	Per Diem Per Traveler	Cost per Trip
DOE Project Review Meeting	Grand Forks	Pittsburgh	2	1	$285	$800	$80	$123	$1,288
Technical Meeting	Grand Forks	Florida	3	2	$420	$800	$80	$185	$2,970
DOE Project Review Meeting	Grand Forks	Pittsburgh	2	1	$285	$800	$80	$123	$1,288
Technical Meeting	Grand Forks	Florida	3	3	$420	$800	$80	$185	$4,455
								Total	**$10,001**

Equipment

A high temperature oven is required to make the anode materials as proposed. A budgetary quote for an oven meeting the requirements of the project is included.

Item	Unit Cost	Qty	Total	Justification
Rotary tube furnace		1	$ 35,000	For carbonization of anode intermediates
Total			**$ 35,000**	

Supplies

A listing of supplies requested for this work is presented below. The cost is estimated based upon previous work on our rare earth project and other related battery development projects.

Item	Cost	Basis	Justification
Chemicals	$ 15,000.00	online pricing	SiO, emulsifiers, and so on
Battery Assembly	$ 15,000.00	online pricing	Components for cell assemble
Stock Gas Bottles	$ 4,500.00	listed vender pricing	Inert gas for sintering
Sample containers	$ 1,000.00	Estimate and online pricing	Cups and vials for sample storage and shipment
Lab Consumables	$ 2,000.00	Estimate and online pricing	Gloves, goggles, weighing paper/boats, etc.

Spray dryer Maintenance	$	3,500.00	Manufacturer Quote	Atomizer, cyclone separator and other accessories
Office Supplies		500	Previous experience	Lab Notebooks, folders, pens/pencils, clips, etc.
Printing Supplies		500	Previous experience	Paper, Ink, Poster Presentation materials
Total		42,000.00		

Fees – Equipment Use and Laboratory Services / Other

A series of laboratory and analytical tests are required to complete the project. The following table gives a breakdown of these costs, with the basis of costs being established equipment use rates at UND, as well as advertised rates various laboratory service providers.

Item	Cost	Basis	Justification
Elemental and TOC analyzer	$3,000	Estimate of total sample number & current per sample rate	Measurement of C, H, O and S Content
Thermogravimetric analyzer (TGA)	$3,000	Estimate of total sample number & current per sample rate	Thermal stability analysis
X-ray Fluorescence spectrometer	$3,000	Estimate of total sample number & current per sample rate	Chemical composition analysis
X-ray diffractometer (XRD)	$3,000	Estimate of total sample number & current per sample rate	Analysis of the crystal structures of SiO and graphite
Scanning Electron Microscope (SEM-EDS)	$5,000	Estimate of total sample number & current per sample rate	Measurement of particle size, porous structure morphology, elemental distribution
BET surface area analyzer	$3,000	Estimate of total sample number & current per sample rate	Surface area, porosity, and pore size analysis of anode particles
Inductively coupled plasma optical emission spectroscopy (ICP-OES)	$3,000	Estimate of total sample number & current per sample rate	Analysis of trace metalic impurities
Electrochemical workstation	$5,000	Estimate of total sample number & current per sample rate	Test the electrochemical properties of anode materials
Total	$28,000		

Subcontracts

N/A

Indirect Costs

The indirect cost rate included in this proposal is the federally approved rate for UND of 41%. The indirect cost method is the Modified Total Direct Cost method, defined as the total direct cost of the project minus equipment in excess of $5000, the first $25,000 of each subcontract in excess of this value, tuition remission, and in-kind cost share contributions.

11. MATCHING FUNDS

Table 6. Matching funds and funding breakdown by support source

Support Source	Cash	In-Kind	TOTAL	% of Project
DOE	$499,815	$0	$499,815	74.7
NDIC	$75,000	$0	$75,000	11.3
NACoal	$45,000	$0	$45,000	6.8
Clean Republic	$7,650	$40,000	$47,650	7.2
TOTAL			**$667,465**	**100**

A breakdown of the funding sources for the project is provided in **Table 6.**

12. TAX LIABILITY

No outstanding tax liabilities to the state of North Dakota

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24. Shen, J. Next Generation Technology for Lithium-Ion-Battery -- Si-C anode and Prelithiation; Fourder Financial: http://chuneng.bjx.com.cn/news/20200306/1051549.shtml, 2020.

15. APPENDICES

15.1 Budget Summary and Budget Justification

The following table gives the summary of the total project budget and the requested funding for each of the cost share partners and the Department of Energy. To simplify the subcontracting and equipment purchases, those costs have been assigned solely to the Department of Energy and only personnel/benefits have been assigned to the cash cost share partners.

Budget Category	Project Total	DOE	NDIC	NACoal	Clean Republic
Personnel	$277,224	$197,422	$43,329	$29,187	$7,286
Fringe Benefits	$65,187	$52,232	$9,863	$2,728	$364
Travel	$10,001	$10,001			
Major Equipment	$35,000	$35,000			
Materials and Supplies	$42,000	$42,000			
Fees	$64,864	$28,000			$36,863
Total direct charges	$494,276	$364,656	$53,192	$31,915	$44,513
F&A	$173,189	$135,158	$21,809	$13,085	$3,137
Total Cost	**$667,465**	**$499,815**	**$75,000.00**	**$45,000.00**	**$47,650.00**
Percent of Total	100.00%	74.70%	11.30%	6.80%	7.20%

Personnel

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

Personnel	Role	Months	Hours	Salary	Fringe	Labor cost
Xiaodong Hou	PI	7.0	1211	50558	17695	68253
Michael Mann	PD	2	347	33143	11600	44743
Yong Hou	Key Personnel	2	347	12032	4211	16243
Robert Ilango	Key personnel	6	1040	22550	7893	30443
Brittany Rew	Key personnel	4.5	780	26167	9158	35325
Sara Ogundonlani	Administrative	3	520	15465	5413	20878
Shuai Xu	Research Assistant	24	2080	33517	3352	36869

Graduate 2	Research Assistant	24	2080	33517	3352	36869
Undergraduate 1	Research Assistant	24	2080	25138	1257	26394
Undergraduate 2	Research Assistant	24	2080	25138	1257	26394
Total				277224	$65,187	$342,411

Fringe Benefits

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

Travel

A breakdown of travel is presented in the table below and includes travel required by DOE to review meetings and sampling field trips. Costs have been estimated based on available airfare and lodging rates, conference fees, standard per diems and other UND travel policy. Estimates are broken down as follows:

Purpose of Travel	Depart From	Destination	No. of Days	No. of Travelers	Lodging per Traveler	Flight per Traveler	Vehicle per Traveler	Per Diem Per Traveler	Cost per Trip
DOE Proejct Review Meeting	Grand Forks	Pittsburgh	2	1	$285	$800	$80	$123	$1,288
Technical Meeting	Grand Forks	Florida	3	2	$420	$800	$80	$185	$2,970
DOE Proejct Review Meeting	Grand Forks	Pittsburgh	2	1	$285	$800	$80	$123	$1,288
Technical Meeting	Grand Forks	Florida	3	3	$420	$800	$80	$185	$4,455
								Total	**$10,001**

Equipment

A high temperature oven is required to make the anode materials as proposed. A budgetary quote for an oven meeting the requirements of the project is included.

Item	Unit Cost	Qty	Total	Justification
Rotary tube furnace		1	$ 35,000	For carbonization of anode intermediates
Total			$ 35,000	

Supplies

A listing of supplies requested for this work is presented below. The cost is estimated based upon previous work on our rare earth project and other related battery development projects.

Item	Cost	Basis	Justification
Chemicals	$ 15,000.00	online pricing	SiO, emulsifiers, and so on
Battery Assembly	$ 15,000.00	online pricing	Components for cell assemble
Stock Gas Bottles	$ 4,500.00	listed vender pricing	Inert gas for sintering
Sample containers	$ 1,000.00	Estimate and online pricing	Cups and vials for sample storage and shipment
Lab Consumables	$ 2,000.00	Estimate and online pricing	Gloves, goggles, weighing paper/boats, etc.
Spray dryer Maintenance	$ 3,500.00	Manufacturer Quote	Atomizer, cyclone separator and other accessories
Office Supplies	500	Previous experience	Lab Notebooks, folders, pens/pencils, clips, etc.
Printing Supplies	500	Previous experience	Paper, Ink, Poster Presentation materials
Total	**42,000.00**		

Fees – Equipment Use and Laboratory Services / Other

A series of laboratory and analytical tests are required to complete the project. The following table gives a breakdown of these costs, with the basis of costs being established equipment use rates at UND, as well as advertised rates various laboratory service providers.

Item	Cost	Basis	Justification
Elemental and TOC analyzer	$3,000	Estimate of total sample number & current per sample rate	Measurement of C, H, O and S Content
Thermogravimetric analyzer (TGA)	$3,000	Estimate of total sample number & current per sample rate	Thermal stability analysis
X-ray Fluorescence spectrometer	$3,000	Estimate of total sample number & current per sample rate	Chemical composition analysis
X-ray diffractometer (XRD)	$3,000	Estimate of total sample number & current per sample rate	Analysis of the crystal structures of SiO and graphite
Scanning Electron Microscope (SEM-EDS)	$5,000	Estimate of total sample number & current per sample rate	Measurement of particle size, porous structure morphology, elemental distribution
BET surface area analyzer	$3,000	Estimate of total sample number & current per sample rate	Surface area, porosity, and pore size analysis of anode particles
Inductively coupled plasma optical emission spectroscopy (ICP-OES)	$3,000	Estimate of total sample number & current per sample rate	Analysis of trace metalic impurities
Electrochemical workstation	$5,000	Estimate of total sample number & current per sample rate	Test the electrochemical properties of anode materials
Total	$28,000		

Subcontracts

N/A

Indirect Costs

The indirect cost rate included in this proposal is the federally approved rate for UND of 41%. The indirect cost method is the Modified Total Direct Cost method, defined as the total direct cost of the project minus equipment in excess of $5000, the first $25,000 of each subcontract in excess of this value, tuition remission, and in-kind cost share contributions.

LAVERN K. LUND
Vice President – Engineering and Business Development

Telephone: 972-448-5400
Email: vern.lund@nacoal.com

June 1, 2020

Dr. Michael D. Mann
Distinguished Professor, Chemical Engineering
Executive Director, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Lithium Ion Battery Anode Materials from Lignite Coals DE-FOA-0002185

Dear Dr. Mann:

The North American Coal Corporation (NACoal) is pleased to support UND's application to US Department of Energy for developing Lithium Ion Battery Anode Materials from lignite coals. We believe your project could help open new markets for the lignite industry and provide our economy with useful, low cost carbon products.

NACoal is the largest lignite producer in the United States and one of the top 10 coal producers in the United States. We mine and market coal for use in power generation, SNG production, activated carbon production, as well as, providing selected value-added mining services for other natural resources companies. Our corporate headquarters are in Plano, Texas, near Dallas, and we operate surface coal mines in North Dakota, Mississippi, Texas, New Mexico, and Louisiana.

NACoal is pleased to provide a total cost-share of up to $45,000, over the 2-year term of the project, subject to project awarded by US Department of Energy and final review.

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

Best of luck on your application.

Very truly yours,

THE NORTH AMERICAN COAL CORPORATION

LaVern K. Lund
Vice President – Engineering and Business Development

CLEAN REPUBLIC
You are the alternative energy

June 24, 2020

Dr. Michael Mann
UND Institute for Energy Studies
2844 Campus Road, Stop 8153
Grand Forks, ND 58202

Re: Support of the proposal entitled "Lignite-derived Carbon Materials for Lithium Ion Battery Anodes" submitted in response to DE-FOA-0002185 "COAL-DERIVED MATERIALS FOR BUILDING, INFRASTRUCTURE, AND OTHER APPLICATIONS"

Dear Dr. Mann:

This letter expresses our support for your project titled "Lignite-derived Carbon Materials for Lithium Ion Battery Anodes" submitted in response to DE-FOA-0002185 "COAL-DERIVED MATERIALS FOR BUILDING, INFRASTRUCTURE, AND OTHER APPLICATIONS" proposal call. This proposal is in direct alignment with our company's goals to develop materials that will increase the capacity, improve the performance, and reduce the cost of lithium ion batteries. We have been very impressed with the advances you have made in the development of cathode materials, and are incorporating some of the results from your previous work into our battery production. We have great hopes that the work proposed here will result in significant advances in anode production, and something we can use to enhance our product line. As a North Dakota company, we are also excited to see you proposing to use North Dakota lignite, which increases the overall value-chain of one of the primary resources of our state. The fact that your work offers the potential to turn this low-cost feedstock into a valuable end product is exciting to us and we see many benefits as we work towards expanding our battery production line in your state.

We would like to support your project financially by offering to pay the wages ($7650) of one undergraduate student assigned to this project, and also provide support for testing of your batteries by giving you access to and helping test your products at our Battery Test Center. The value of this battery testing support was estimated at $20,000 per year for the two years of your project. Therefore, we estimated the total value of our support for this project is $47, 650. We will also be available for meetings, consultation, and other exchange as needed to help your project progress.

We are looking forward to working with you on this new venture. As always, don't hesitate to call with any questions.

Sincerely

Michael Shope
CTO - Clean Republic LLC

North Dakota Office: 5515 University Avenue, Grand Forks, ND 58203
Email: info@cleanrepublic.com Phone: 218 779 3136

Lignite Energy Council

July 8, 2020

Dr. Xiaodong Hou
UND Institute for Energy Studies
2844 Campus Road, Stop 8153
Grand Forks, ND 58202

Re: Support of the proposal entitled "Lignite-derived Carbon Materials for Lithium Ion Battery Anodes" submitted in response to DE-FOA-0002185: "Coal-Derived Materials for Building, Infrastructure, and Other Applications"

Dear Dr. Hou:

The Lignite Energy Council (LEC) is pleased to support your proposed efforts to prepare microspherical SiO/G/C (silicon monoxide/graphite/carbon) composite anodes that leverages the unique properties of silicon monoxide, lignite-derived pitch and synthetic graphite. We are always excited to see proposals that provide the opportunity to produce high value-added products from North Dakota resources. Your project which seeks to maximize the value of coal is a good fit with the mission of the Lignite Energy Council.

We are pleased to see the support this project has received from your industry partners, North American Coal Corporation and Clean Republic. As a part of this project, the Lignite Research Program will provide $75,000 in cash cost share to match that provided by your industry partners. The cost share will be provided over the 2-year project duration and is subject to a project award by the US Department of Energy. The cash support will be contingent upon submission of a proposal to the North Dakota Lignite Research Program and subsequent approval by the Lignite Research Council and the North Dakota Industrial Commission. It is understood that this Lignite Research Program funding will provide cost share to federal funding from the U.S. Department of Energy (DOE); therefore, Lignite Research Council certifies that its cost-share funding will comprise nonfederal dollars and will not be used as federal match on any other project.

We hope that DOE gives careful consideration to this project as we feel that if successful, it will significantly contribute to the development and deployment of new high-value markets for North Dakota lignite. Again, we express our interest in and support of the project and look forward to working with DOE and project co-sponsors and advisors on this important project.

Sincerely,

Mike Holmes
Vice President of Research & Development
Lignite Energy Council

MICHAEL D. MANN, PhD

Executive Director, Institute for Energy Studies

Education and Training

Mayville State University	Chemistry, Mathematics	B.A., 1979
University of North Dakota	Chemical Engineering	M.S., 1981
University of North Dakota	Business Administration	M.B.A., 1987
University of North Dakota	Energy Engineering	Ph.D., 1997

Research and Professional Experience

2014 –Present: Executive Director, Institute for Energy Studies:

2009-14: College of Engineering (Associate Dean 2013-14; Associate Dean for Research 2009-13)

2008: Interim Dean, UND School of Engineering and Mines

1999 – Present: UND Department of Chemical Engineering (Professor, 2006-present; Chair 2005-13; Associate Professor, 1999-2006)

1981-99: UND Energy & Environmental Research Center (Sr. Research Mgr, Advanced Processes and Technologies 1994-99; Research Mgr, Combustion Systems 1985-94; Research Engineer 1981-85)

PUBLICATIONS (selected from over 150)

- Michael Mann, Daniel Laudal, and Steve Benson, "Maintaining Coal's Prominence in a Carbon Constrained World", Keynote presentation: 2017 International Conference of Coal Science & Technology, Sept 2017.
- Daniel Laudal, Brittany Rew, Steve Benson and Michael Mann, "Technical and Economic Feasibility Analysis of Integrating Activated Carbon with Heating Plant", 2017 International Pittsburgh Coal Conference, Sept 2017
- Mann, M.D.; Knutson, R.Z.; Erjavec, J.; Jacobson, J.P.; "Modeling Reaction Kinetics for a Transport Gasifier", *Fuel* 83 2004 1643-1650.
- Dahal, S.; Salehfar, H.; Gosnold, W.; Mann, M.; "Modeling and Simulation of the Interface between Geothermal Power Plant Based on Organic Rankine Cycle and the Electric Grid," GRC, Oct. 2010

- Dale, N.N.; Mann, M.D.; Salehfar, H.; Dhirde, A.M.; Han, T.; "ac Impedance Study of a Proton Exchange Membrane Fuel Cell Under Various Loading Conditions", Journal of Fuel Cell Science and Technology, 7 (2010) 031010.
- U.S. Patent Number 6,053,954, Methods to Enhance the Properties of Hydrothermally Treated Fuels, 2000
- C.Y. Biaku, N.V. Dale, M.D. Mann, H. Salehfar, A.J. Peters, T. Han; "A semiempirical study of the temperature dependence of the anode charge transfer coefficient of a 6 kW PEM electrolyzer" International Journal of Hydrogen, 22 (2008) 4247-4254
- Karki, S., Mann, M.; Salehfar, H.; "Substitution and Price Effects of Carbon Tax on CO2 Emission Reduction from Distributed Energy Sources", *Asian Journal of Energy & Environment"*
- Bandyopahdyay, G.; Bagheri, F.M.; Mann, M.D.; "Reduction of Fossil Fuel Emission in US: A Holistic Approach Towards Policy Formulation", *Energy Policy*; 2007, 35 (2) 950-965.
- Karki, S; Kulkarni, M.; Mann, M.D.; Salehfar, H.; "Efficiency Improvements through Combined Heat and Power for On-Site Distributed Generation Technologies", *Cogeneration and Distributed Generation Journal*, Vol 22, No 3, 2007, pp 19-34.

SYNERGISTIC ACTIVITIES

Dr. Mann's principal areas of expertise include multidisciplinary and integrated energy and environmental projects emphasizing a cradle-to-grave approach; development of energy strategies coupling thermodynamics with political, social, and economic factors; selection of optimum utilization processes emphasizing renewable energy and clean coal technologies; and integration of effluent treatment and emission controls.

Major active projects include "Preparation of Graphene-Modified $LiFePO_4$ Cathode for Li-ion Battery", "Investigation of Rare Earth Element Extraction from North Dakota Coal Related Feedstocks", and "Commercialization of the Sandwich Gasifier".

Currently Lead of UND's campus wide Energy & Environmental Sustainability Grand Challenge Team

Xiaodong Hou Ph.D.

Institute for Energy Studies, College of Engineering & Mines, University of North Dakota

EDUCATION AND TRAINING

2010-2013 **Postdoctoral**, Chemistry Department, University of North Dakota, Grand Forks, ND, USA.

2009 **Ph.D. Polymer Chemistry and Physics**, Shanghai Jiao Tong University, Shanghai, China.

2005 **M.S. Chemical Engineering**, Shaanxi University of Science and Technology, Shaanxi, China.

2002 **B.S. Chemical Engineering**, Shaanxi University of Science and Technology Shaanxi, China

RESEARCH AND PROFESSIONAL EXPERIENCE

2017- **Research Assistant Professor** Institute for Energy Studies (IES), UND. Research Interests: development of advanced materials for Li-ion batteries, and coal-derived high-value carbon materials.

2014-2016 **Senior Chemist/Lecturer** Advanced Material Characterization laboratory, Institute for Energy Studies, UND. Main research interests and expertise: synthesis and characterization of advanced chemical materials, environmental sampling and analysis, and crystal structural analysis.

2013-2014 **Interim Lab Director** and **Analytical Chemist** Environmental Analytical and Research Laboratory, UND. Principal areas of expertise: apply various spectroscopic, chromatographic and microscopic techniques to determine the chemical components of broad environment samples.

2010-2013 **Postdoctoral Research Associate** Chemistry Department, UND. Research interests: synthesis and characterization of covalently bonded hierarchical nanomaterials.

2005-2009 **Ph.D. Graduate Research Assistant** Shanghai Jiao Tong University, Shanghai, China. Research interests: Synthesis and characterization of advanced inorganic nanoparticles/block copolymer hybrid materials for energy application.

PUBLICATIONS (Selected from over 30)

1. **Hou, X.**; Hou, Y.; Mann, M. *Porous Silicon/Lignite-derived Graphene Composite Anodes for Lithium*

ion batteries, 36th International Battery Seminar and Exhibition, Fort Lauderdale, FL, March 24-27; Fort Lauderdale, FL, **2019**.

2. Baker, J.; Xu, S.; Mann, J.; Dockter, A.; Hou, Y.; Mann, M.; **Hou, X.** *Preparation of Lithium Ion Battery Cathode Composites Using Leonardite-Derived Humic Acid*, 2018 AIChE Annual Meeting, Pisttburg, PA. October 26-29, **2018**.

PATENTS

1. **Xiaodong Hou.** Low-cost Graphene-modified Anode Materials for Lithium Ion Batteries. Provisional Patent in process.

SYNERGISTIC ACTIVITIES

- Dr. Hou's is the group lead of lithium-ion-battery research at IES, the major active projects include "The Preparation of a High Capacity Graphene Modified Graphite /SiOx Anode Electrode for Mic-Power' Button Batteries", awarded $259,796 by Micro-power New Energy Co., Ltd. "Porous Silicon/Lignite-Derived Graphene Composite Anodes for Lithium-Ion Batteries", awarded $369,581 by DOE UCFER. "Lignite-Derived Graphene/Si Nanocomposite Anode for Li-ion Battery", awarded $140,000 by UND VPR Post-Doctoral Program. "Freestanding Lignite-derived Graphene-based Foam Anode for Lithium ion Battery", awarded $10,000 by ND EPSCoR. "Preparation of Graphene-Modified $LiFePO_4$ Cathode for Li-ion Battery", Award $486,238 by NDIC/Clean Republic LLC.
- Invited lecture & Presentations. "Coal-derived Carbon Materials for Lithium Battery" in UND physics department, Sept 2019. "A Low-Cost Synthetic Procedure for High Consistent $LiFePO_4$ Cathode Materials" in conference "Lithium Battery Materials & Chemistry/ Battery Safety 2017", Arlington, Virginia, Oct 30 – Nov 2, 2017.

DENNIS R. JAMES

The North American Coal Corporation

EDUCATION AND TRAINING:

2001-2002 **M.B.A School of Business,** University of Mary, Bismarck, North Dakota.

2000-2001 **M.M. School of Business,** University of Mary, Bismarck, North Dakota.

1975-1977 **M.S. Geosciences,** Purdue University, West Lafayette, Indiana.

1972-1975 **B.S. Geology,** Youngstown State University, Youngstown, Ohio.

RESEARCH AND PROFESSIONAL EXPERIENCE:

2007-Present Director - New Technology: Assist customers to solve plant performance issues that relate to coal quality and coal use. Help new and existing customers to select, design, and size technologies and processes to be compatible with a particular coal reserve. Evaluate and develop new business opportunities. Evaluate and develop new technologies that have the potential to create new business opportunities and/or improve current business operations for NACoal or its customers. Interface with universities and companies on R&D projects

1997-2007 **Staff Geologist and Fuel Quality Administrator:** Manage geologic and ground water databases to support engineering and meet regulatory requirements. Assist customers with process improvement and troubleshooting at power plants. Develop blending programs for coal feed to power plants to better utilize the coal reserve and deliver consistent, predictable fuel qualities.

1989-1997 **Senior Geologist:** Plan and conduct geologic drilling programs. Develop models with the geologic data. Manage the ground water program to support regulatory requirements. Work with engineering and operations on coal quality plans and issues.

1987-1989 **Senior Geologist – Special Projects:** Support North Dakota mines by conducting geologic drilling programs and building geologic models to define the reserve. Manage company's core sample warehouse. Develop cash flow analyses to support upper management

1986-1987 **Senior Geologist – Exploration:** Evaluate new coal reserves and make recommendations.

Plan and supervise geologic drilling programs. Use computer models of geologic data to define coal reserves.

1981-1986 **Senior Mine Geologist:** Plan and conduct geologic drilling programs to support new mine development and operations. Assist operations in planning and executing coal quality blending. Evaluate and implement geotechnical plans to minimize slope stability issues.

PATENTS:

Method of Enhancing the Quality of High-Moisture Materials Using System Heat Sources

AWARDS:

2009 **American Institute of Professional Geologists (AIPG) Presidential Award of Merit** for work on the AIPG Energy Policy (Coal Chairman)

2005 **North Dakota Lignite Energy Council Distinguished Service Award, R&D,** for work developing technologies to remove mercury from lignite-fired emissions

2002 **North Dakota Lignite Energy Council Distinguished Service Award, Government Affairs,** for work with EPA on Mercury MACT issues

ADVISORY BOARDS AND COUNCILS:

2016-Present **National Coal Council** – Appointed by the US Department of Energy Secretary. Advisory council to the Secretary. Provide input and reports as requested by the Secretary

2017-Present **University of Texas – Dallas, School of Management, Energy Advisory Council** - The Council advises UTD's new Energy Management Program on matters of program direction and curriculum; along with other matters as requested. In addition, providing mentorship to students

Yong Hou, Ph.D.

Email:hou@cleanrepublic.com Phone: 218-791-3746

EDUCATION BACKGROUND

2007 **Ph. D.** Systems Engineering, University of Shanghai for Science and Technology, China

1992 **M.S.** Systems Engineering, University of Shanghai for Science and Technology, China

1983 **B.S.** Electronics Engineering, Hunan University of Art and Science, China

RESEARCH AND PROFESSIONAL EXPERIENCE

2008-present **Co-founder, VP for Research,** Clean Republic SODO LLC, Grand Forks, ND

Direct the development and production of advanced electrode materials for Li-ion battery and Li-ion battery packs

2008~2012 **Adjunct Professor** Department of Technology, University of North Dakota

2007~2008 **VP for Product Development** Neosonic Li-Polymer Energy Co., Zhuhai, China

Direct the development of new Li-Polymer battery using for light electric vehicles, and Direct the Neosonic business department, ERP system and testing Laboratory

1995-2002 **Founder/General Manager** Shanghai Zhongdian International Company, China

Founded and turn the company's PC service business into the No.1 wholesaler of Compaq Computers in China with an annual revenue of $13M and 50+ employees

1992-1995 **Department Manager** Shanghai Branch Company of Chinese Electronics Group

1983-1989 **Electronics Engineer** Hunan Puyuan Engineering Machinery Company, China

PUBLICATIONS

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

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

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

4. ZHU Hongbo, GAO Yan, HOU Yong, TAO Li; "Real-time pricing strategy for smart grid based on Markov decision processes"; Systems Engineering – Theory and Practice; Dec. **2017**

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

PATENTS

Yon Hou. A New Control System and Lithium Ion Battery Pack for Hybrid E-Bike (China Patent: 2017205084553)

SYNERGISTIC ACTIVITIE

1. As the principal investigator, Dr. Yong Hou's is leading a project titled "The Preparation of a High Capacity Graphene Modified Graphite /SiOx Anode Electrode for Mic-Power' Button Batteries", awarded $259,796 by Micro-power New Energy Co., Ltd., Period: 7/1/2020 – 9/30/2021.
2. As the Co-PI, Dr. Yong Hou completed the project "A Low Cost and Reproducible Synthetic Procedure for Mass Production of LiFePO4 Cathode Materials for Li-ion Batteries", Funding sources: NDIC, Amount: $246,988, Total Award Period Covered: 1/1/2017-12/31/2017.
3. As the Co-PI, Dr. Yong Hou is conducting the project "Preparation of Graphene-Modified LiFePO4 Cathode for Li-ion Battery", Funding sources: NDIC, Amount: $490,139, Total Award Period Covered: 2/1/2018-1/31/2020.
4. As the principal investigator, Dr. Yong Hou is leading the project "Advanced Integrated Solar-LFP Battery Powered Water Pump System for Remote Farm fields". NDIC, Amount: $30,000, Total Award Period: 5/01/2018 – 4/30/2019.

Brittany J. Rew

Engineer, Institute for Energy Studies,

University of North Dakota, Grand Forks, ND 5802

Education and Training

University of North Dakota	Chemical Engineering	B.S. 2017
University of North Dakota	Chemical Engineering	M.S. 2020 (Expected)

Research and Professional Experience

2018-Present Engineer, UND Institute for Energy Studies

Primary roles include process design, testing and operation, and analysis of novel processes on the lab, bench, and pilot-scale. Research areas include rare earth element recovery from coal and coal byproducts and development of coal-derived carbon materials. Principle Investigator on a project aimed at developing a low-cost method to analyze and sort rare earth element feedstock materials.

2017-2018 Junior Engineer, UND Institute for Energy Studies

Research areas included rare earth element recovery from coal and coal byproducts, chemical looping combustion, and CO_2 capture systems. Work included process design and testing of equipment on the lab and bench scale.

Synergistic Activities

Ms. Rew has experience with process and equipment design and has worked with lab, bench, and pilot-scale systems. She has been involved in the development of a techno-economic assessment as part of a project for a rare earth element (REE) recovery process from North Dakota lignite coal (DE-FE0027006).

Robert Ilango Ph.D.

Institute for Energy Studies,

College of Engineering & Mines, University of North Dakota

CEC-246, Grand Forks, ND58202-8153

701-885-9378, roberti.pushparaj@und.edu

EDUCATION AND TRAINING

2016 **Ph.D. Chemical Engineering,** Kyung Hee University, Suwon, South Korea

2005 **M.Sc. Nanoscience and Technology**, Bharathiar University, Coimbatore, India

2002 **B.Sc. Physics,** Ananda College affiliated to Alagappa University, India

RESEARCH AND PROFESSIONAL EXPERIENCE

2020- Present, **Postdoctoral Research Fellow** Institute for Energy Studies (IES), University of North Dakota, USA. Research Interests: Synthesis and characterization of low-cost Si/G for Li-ion battery.

2018-2020 **Postdoctoral Research Fellow** Nanjing University of Aero and Astronautics, China. Research area: Construction of nanofibers via electrospinning for Li/Na-storage and electrocatalysis.

2016-2018 **Postdoctoral Research Fellow** National Tsing Hua University, Taiwan. Research area: Evaluation of TMD compounds MX_2 (M = Mo, Ti, V or W, X = S, Se and Te) material for the applications of Li-ion, dye Adsorbent and electrocatalyst.

2012-2016 **Ph.D Research:** Kyung Hee University , South Korea ***Title:*** Design and characterization of coating and electrode materials for rechargeable Li-ion batteries.

PUBLICATIONS

3. G. Yang, **P. Robert Ilango,** Silan Wang, Muhammad Salman Nasir, Linlin Li, Dongxiao Ji, Yuxiang Hu, Seeram Ramakrishna, Wei Yan* and Shengjie Peng*, "Carbon-Based Alloy-Type Composite Anode Materials toward Sodium-Ion Batteries", *Small* 15 **(2019)** 1900628 https://onlinelibrary.wiley.com/doi/abs/10.1002/smll.201900628

4. Po-Jen Yen, **P. Robert Ilango,** Ya-Chi Chiang, Wu-Chia Wei, Yung-Chi Hsu,Yu-Lun Chueh, Kung-Hwa Wei, "Tunable nitrogen-doped graphene sheets produced with In-situ electrochemical cathodic plasma processing at room temperature for lithium-ion batteries". *Materials Today Energy* 12 ***(2019)*** 336-347 https://www.sciencedirect.com/science/article/pii/S2468606918302715
5. **P. Robert Ilango,** K. Prasanna, Yong Nam Jo, P. Santhoshkumar, Chang Woo Lee*, Synthesis and characterization of nanocrystalline $ZnWO_4$ anode materials for rechargeable Li-ion batteries, *Materials Chemistry and Physics 207* **(2018)** *367-372.* https://www.sciencedirect.com/science/article/pii/S0254058417310301
6. **P. Robert Ilango,** K. Prasanna, Su Jung Do, Yong Nam Jo, Chang Woo Lee*, Eco-friendly nitrogen-containing carbon encapsulated $LiMn_2O_4$ cathodes to enhance the electrochemical properties in rechargeable Li-ion batteries, *Scientific Reports,* 6 **(2016)** 29826 https://www.nature.com/articles/srep29826
7. **P. Robert Ilango,** K. Prasanna, T. Subburaj, Yong Nam Jo, Chang Woo Lee*, Facile longitudinal unzipping of carbon nanotubes into graphene and their effects on $LiMn_2O_4$ cathodes in rechargeable lithium-ion batteries, *Acta Materialia* 100 **(2015)** 11-18 https://www.sciencedirect.com/science/article/pii/S1359645415005935

SYNERGISTIC ACTIVITIES

1) Given a lecture in the title of 'Recent Technologies Using Li-Ion Batteries' at Arul Anandar College (Autonomous), Karumathur, Madurai, India, on 03-10-2016

2) Given a lecture in the title of 'Physics Research Advancements and Scenario in India and Foreign Countries' at Ananda College, Devakottai, Affiliated to Alagappa University, India, on 07-10-2016

3) Given a lecture in the title of 'Higher Education and Career Planning' at Sree Arumugham Arts and Science College, Affiliated to Tiruvalluvar University, India, on 27-09-2016

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EDUCATION AND TRAINING

2018- **Ph.D. Energy Engineering**, IES, University of North Dakota, Grand Forks, ND, USA

2016 **M.S. Chemical Process**, Guangxi University, Guangxi, China.

2012 **B.S. Applied Chemistry**, Hainan University, Hainan, China

RESEARCH AND PROFESSIONAL EXPERIENCE

2018- **PhD Research**

Research area: Synthesis and characterization of advanced cathode and anode materials for lithium-ion batteries. Including developing cathode materials with well dispersed, high conductive powder, by low cost, facile synthesis process; designing Si-based anodes with hierarchical structures that could alleviate the huge volume change of silicon composites during cycling and prevent the reaction of silicon and electrolyte; synthesizing and characterizing Si-based composites with high-performance and long life, optimizing parameters during synthesis processes; scaling-up for commercial application.

2016-2018 **R&D Engineer**, Ningbo Fuli Battery Materials Technology Co., Ltd, Advanced Li-ion Battery Engineering Lab, CNITECH, Ningbo China. In charge of designing, synthesizing, charactering, improving Si/C anodes; Build and optimize pilot-scale synthesis of SiO/C anodes.

2013-2016 **MS research**

Research interests focus on the development of high energy density $LiMnPO_4/C$ cathode materials, design of high porous and conductive micro particle structure, build-up of simple and low-cost synthesis process, synthesis and characterization of nano cathode materials.

PUBLICATIONS

8. Baker, J.; **Xu, S.**; Mann, J.; Dockter, A.; Hou, Y.; Mann, M.; Hou, X. In Preparation of Lithium Ion Battery Cathode Composites Using Leonardite-Derived Humic Acid, 2018 AIChE Annual Meeting, Pisttburg, PA. October 26-29, 2018. https://www.aiche.org/conferences/aiche-annual-meeting/2018/proceeding.

9. **Xu, S.**; Lv, X.-Y.; Wu, Z.; Long, Y.-F.; Su, J.; Wen, Y.-X. Synthesis of porous-hollow LiMn0. 85Fe0. 15PO4/C microspheres as a cathode material for lithium-ion batteries. *Powder Technology* **2017**, *308*, 94-100. https://www.sciencedirect.com/science/article/pii/S0032591016308695

SYNERGISTIC ACTIVITIES

1) As a PhD candidate and research assistant, Shuai Xu is participating the project "Porous Silicon/Lignite-Derived Graphene Composite Anodes for Lithium-Ion Batteries", Funding Sources: DOE UCFER, Amount: $369,581, Total Award Period Covered: 11/1/2019 – 4/30/2021.
2) As a PhD candidate and research assistant, Shuai Xu is participating the project "Preparation of Graphene-Modified $LiFePO_4$ Cathode for Li-ion Battery", Funding sources: NDIC/Renewable Energy Council/Clean Republic LLC, Amount: $486,238, Total Award Period Covered: 2/1/2018-1/31/20.
3) As a R&D engineer, Shuai Xu participated design, characterization optimization and synthesis of SiO/C anodes, porous Si anodes and Si/C associated electrolytes. Working institute: Ningbo Fuli Battery Materials Technology Co., Ltd., 7-5-2016 – 3-30-2018.