CLEAN RESOURCES FINAL REPORT PACKAGE

Project proponents are required to submit a Final Report Package, consisting of a Final Public Report and a Final Financial Report. These reports are to be provided under separate cover at the conclusion of projects for review and approval by Alberta Innovates (AI) Clean Resources Division. Proponents will use the two templates that follow to report key results and outcomes achieved during the project and financial details. The information requested in the templates should be considered the minimum necessary to meet AI reporting requirements; proponents are highly encouraged to include other information that may provide additional value, including more detailed appendices. Proponents must work with the AI Project Advisor during the preparation of the Final Report Package to ensure submissions are of the highest possible quality and thus reduce the time and effort necessary to address issues that may emerge through the review and approval process.

Final Public Report

The Final Public Report shall outline what the project achieved and provide conclusions and recommendations for further research inquiry or technology development, together with an overview of the performance of the project in terms of process, output, outcomes and impact measures. The report must delineate all project knowledge and/or technology developed and must be in sufficient detail to permit readers to use or adapt the results for research and analysis purposes and to understand how conclusions were arrived at. It is incumbent upon the proponent to ensure that the Final Public Report **is free of any confidential information or intellectual property requiring protection**. The Final Public Report will be released by Alberta Innovates after the confidentiality period has expired as described in the Investment Agreement.

Final Financial Report

The Final Financial Report shall provide a complete and accurate accounting of all project expenditures and contributions over the life of the project pertaining to Alberta Innovates, the proponent, and any project partners. The Final Financial Report will not be publicly released.

Development of Asphaltene-Based Carbon Fibers

Public Final Report

Prepared for

Alberta Innovates

Prepared by

Auburn University

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CLEAN RESOURCES FINAL PUBLIC REPORT TEMPLATE

1. PROJECT INFORMATION:

Project Title:	Development of Asphaltene-Based Carbon Fibers
Alberta Innovates Project Number:	G2020000341
Submission Date:	March 15th, 2021
Total Project Cost:	$75,500
Alberta Innovates Funding:	$50,000
AI Project Advisor:	Paolo Bomben

2. APPLICANT INFORMATION:

Applicant (Organization):	Auburn University
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3. PROJECT PARTNERS

Please provide an acknowledgement statement for project partners, if appropriate.

A. EXECUTIVE SUMMARY

Provide a high-level description of the project, including the objective, key results, learnings, outcomes and benefits.

The purpose of this project is the development of asphaltene-based carbon fibers. The specific objectives are as follows: a) pretreat the asphaltene to improve its extrudability and morphology retention, b) extrude and carbonize the asphaltene as received and pretreated, and c) identify partners for phase II of the project with graphitization and scale-up capabilities. Both the pretreatment and extrusion of the asphaltenes were successful, and the carbonization shows an improved morphology for the pretreated asphaltene compared to the asphaltene as received. By doing further research on the asphaltene to carbon fiber development and as this process begins to scale up, new value-added streams for current industry, development of new entrepreneurial opportunities, and the retention and attraction of highly qualified and skilled personnel can be expected.

B. INTRODUCTION

Please provide a narrative introducing the project using the following sub-headings.

- **Sector introduction:** Include a high-level discussion of the sector or area that the project contributes to and provide any relevant background information or context for the project.
- **Knowledge or Technology Gaps:** Explain the knowledge or technology gap that is being addressed along with the context and scope of the technical problem.

Sector Introduction

Asphaltene is a macromolecule with a large molecular weight. It is a component found in crude oil that is known to cause issues during the transportation of crude oil. During transportation, the asphaltene can build up, causing clogs to occur in the pipeline if not properly removed [1]. Should the asphaltene deposit onto the pipeline, it must be removed; mechanical, ultrasonic, and chemical treatments are known methods used to remove the asphaltene build-up. Currently, there is little use for the material, though it is a component in asphalt used for paving roads [2]. Due to the need to remove the material from the crude oil and the lack of applications, there has been research for the development of new products, including carbon fiber, based on asphaltene.

Knowledge of Technology Gaps

A significant issue of asphaltene is its chemical makeup. Due to its nature as a large macromolecule, the exact chemical makeup of asphaltene is unknown. In addition to that, there are a wide variety of chemicals that make up asphaltene. There are large molecular structures, but there is also low molecular weight volatiles that can cause issues for product development. This lack of a distinct chemical can make it challenging to produce new products, such as carbon fiber. A better understanding of asphaltene properties will help inform the manufacture of carbon fiber and that is the focus of this project.

C. PROJECT DESCRIPTION

Please provide a narrative describing the project using the following sub-headings.

- **Knowledge or Technology Description:** Include a discussion of the project objectives.
- **Updates to Project Objectives:** Describe any changes that have occurred compared to the original objectives of the project.
- **Performance Metrics:** Discuss the project specific metrics that will be used to measure the success of the project.

Knowledge or Technology Description

This project has three major objectives.

The first objective is the pretreatment of the asphaltene. The asphaltene as received possesses a large quantity of low molecular weight volatiles, which can cause issues during the carbonization process. This objective also involves the characterization of the asphaltene as received as well as the pretreated asphaltenes. The purpose of this objective was to understand the material properties and chemical makeup better. This will provide information on what is occurring during the pretreatment process and what the resulting materials are.

The second objective is the extrusion of the asphaltene as received and pretreated asphaltene. This is to provide the fiber morphology from the asphaltene, which is important for developing the carbon fiber.

The last objective is the stabilization and carbonization of the asphaltene fibers.

Updates to Project Objectives

No additional updates

Performance Metrics

There are three project-specific metrics that were used in determining the success of the project. The first metric is the pretreatment of the asphaltene samples. This metric had one subgoal: chemical separation of impurities and thermal treatment of asphaltene.

The second metric is the fabrication of carbon fibers. This metric had three subgoals: fabrication of melt-spun asphaltene fibers, stabilization and carbonization of asphaltene fibers, and characterization of carbon fibers.

The third metric is identifying partners for graphitization and scale-up purposes for the phase II portion of the project. This metric did not have any subgoals.

D. METHODOLOGY

Please provide a narrative describing the methodology and facilities that were used to execute and complete the project. Use subheadings as appropriate.

Pretreatment of Asphaltene

The pretreatment of asphaltene was performed utilizing a 4843 Parr reactor. Both compressed nitrogen and air were attached to the reactor to allow the chamber to be purged during the pretreatment. These methods were based on Qin et al. [3]

Five different pretreatment methods were performed. These can be seen below in Table 1.

Table 1- Asphaltene Pretreatment Methods

Method Number	Procedure
M-1	30 min., 220^{o}C, Air
M-2	30 min., 220^{o}C, Air 1 hour, 300^{o}C, Air
M-3	30 min., 220^{o}C, Air 4 hours, 300^{o}C, Air
M-4	30 min., 220^{o}C, Air 4 hours, 300^{o}C, Air 2 hours, 350^{o}C, Nitrogen
M-5	30 min., 220^{o}C, Air 4 hours, 300^{o}C, Air 4 hours, 350^{o}C, nitrogen

Energy Dispersive Spectroscopy (EDS)

Elemental analysis was performed on the asphaltene as received and the five different pretreated samples to determine the elemental composition of the materials. This was done using a Zeiss Evo 50 Scanning Electron Microscope and an INCA Energy Dispersive Spectroscopy. The material was attached to carbon tape on an aluminum stub. The aluminum stub was then sputter-coated with gold. Last, the aluminum stubs and an aluminum stub with a piece of copper tape were placed into the SEM.

In order to use the EDS, a scan of the copper tape was used to calibrate the machine. After the calibration, three different scans of each sample were made in order to get the elemental composition of the different materials.

Fourier-Transform Infrared Spectroscopy

Fourier-Transform Infrared Spectroscopy (FTIR) was used to determine chemical groups in the asphaltene as received and the five different pretreated materials. A Nicolet 6700 FTIR spectrometer from Thermo Scientific (USA) in attenuated total reflection (ATR) infrared mode was utilized to study the FTIR spectra of the synthesized samples. The wavenumber range was between 4000 cm^{-1} to 400 $cm^{-1,}$ and 64 scans with a resolution of 4 cm^{-1} were taken for each sample.

^{1}H-Nuclear Magnetic Resonance

The ^{1}H-Nuclear Magnetic Resonance (^{1}H-NMR) spectra were obtained with Bruker 600 MHz NMR spectrophotometer. Around 0.4 mg of sample was dissolved in 1000µl of deuterated chloroform ($CDCl_3$) containing tetramethylsilane (TMS). Each spectrum was recorded with 16 scans and 65536 transients. Further, the data were analyzed using Mnova V.14 software.

Thermal Characterization

The thermal stability of the asphaltene as received and the five different pretreatment methods were characterized using a TA Instruments TGA Q500. In order to analyze the samples, the TGA was set to increase the temperature at a rate of 10ºC/min until it reached 850ºC. This was done under a nitrogen atmosphere to prevent combustion reactions.

Rheology

An AR-G2 TA Universal Rheometer with parallel plate geometry (25 mm disposable aluminum plates) was used to perform a strain sweep test on asphaltene as received and temperature sweep tests on asphaltene as received and asphaltene pretreated with methods 1 and 2. Temperature calibration was performed between 100°C and 250°C to account for the expansion of the plates. The strain sweep test was performed on asphaltene as received between 0.1% and 100% strain at 200°C with a frequency of 1 Hz. Temperature sweep tests were performed on asphaltene as received and asphaltene pretreated with methods 1 and 2 from 250°C to 100°C at a rate of 5°C/minute with a strain of 0.5% and a frequency of 1 Hz.

Extrusion

The asphaltene as received as well as M-1 and M-2 asphaltene, were extruded using an Automatik Machinery Corporation Single-Screw Extruder (USA). The extruder has a feeder with a water jacket for cooling and two different heating elements. For the extrusion, each heating element was set to 150ºC, and the screw spun at 15 RPM to move the materials. Each sample was manually loaded to prevent a torque overload from shutting down the extrusion process while maintaining the 15 RPM. The material that was extruded was manually drawn. A custom die was manufactured with a 1 mm diameter and a length to diameter ratio of 3. After collection, the material was allowed to be cooled before being collected

Carbonization

The carbonization of the extruded asphaltene samples using a Thermo Scientific Lindberg Blue M tube furnace. The furnace was attached to a tank of compressed nitrogen gas. In order to carbonize the material, the furnace was increased to 220ºC at a rate of 3ºC/min. The temperature was then increased to 280ºC at a rate of 0.5ºC/min and isotherm for 2 hours. After the isotherm, the temperature was increased to 1000ºC at a rate of 5ºC/min and isotherm for 15 minutes. After this, the samples were cooled to room condition ambiently. This process was based on Qin et al [3].

The extruded asphaltene samples and the carbonized asphaltene samples were then visually inspected using a Zeiss Evo 50 Scanning Electron Microscope, the same SEM used in the EDS analysis.

E. PROJECT RESULTS

Please provide a narrative describing the key results using the project's milestones as sub-headings.

- Describe the importance of the key results.
- Include a discussion of the project specific metrics and variances between expected and actual performance.

a) Pretreatment of Asphaltene

All five of the pretreatment methods and some differences were notable during asphaltene collection. M-1 asphaltene was a homogenous material that required heating to be removed from the reactor. M-2 asphaltene had two phases. The first was a brittle portion near the top of the reactor, and the second was a homogenous material at the bottom of the reactor; the brittle portion did not require heating to be removed, whereas the bottom portion required heating. M-3, M-4, and M-5 were all brittle materials that did not require heating to be removed.

Energy Dispersive Spectroscopy

The EDS showed how the elemental makeup changed between the different pretreatments. The highest elemental percentage for all materials, both asphaltene as received and the pretreated asphaltene, was carbon, as expected. The following two elements that took up the remaining percentage were oxygen and sulfur. The EDS that was used could not detect features lower than carbon on the periodic table.

The EDS showed a significant change in the oxygen during the pretreatment. The oxygen percentage increased between asphaltene as received to M-1, M-2, and M-3. M-3 had the most significant percentage of oxygen. M-4 showed a large decrease in the oxygen content, which corresponds with the switch from using compressed air to using compressed nitrogen in the Parr reactor. Low molecular weight oxygen compound is believed to have formed during M-1, M-2, and M-3 from the compressed air interacting. Due to switching to nitrogen, the compounds no longer formed and were removed like the other low molecular weight compounds from the beginning. The oxygen content in M-5 remained similar to M-4. The sulfur content for all of the samples remained identical.

Fourier-Transform Infrared Spectroscopy

Each of the samples showed peaks at 2900 cm^{-1} relating to =C-H bonds. This type of bond was also seen at 810 cm^{-1}. C=C bond was shown at 1600 cm^{-1}. For samples M-1, M-2, M-3, peaks were shown between 1400 cm^{-1} to 900 cm^{-1} O-C bonds. These bonds were not as present in the asphaltene as received or the M-4 and M-5 asphaltene. This supports the theory of oxygen-containing compounds were forming during the pretreatment under compressed air and were removed when the air was switch to nitrogen.

^{1}H-Nuclear Magnetic Resonance

Each of the samples showed peaks at two regions. The aliphatic region is observed between 0.5 and 4.5 ppm, and the 6.5 and 9.0 ppm region belongs to aromatic hydrogens. The aliphatic region is further broken into the aliphatic area, belongs to lower ppm, and the alicyclic area in higher ppm. Surprisingly, no considerable difference was observed in any of the asphaltene sample peaks.

Thermal Characterization

The TGA showed the effect of the pretreatment on the asphaltene thermal stabilization. The lowest weight percentage out of all after the TGA was asphaltene as received, which was expected. Both M-1 and M-2 had increased weight percentages, with M-2 have the highest weight percentage out of all three. M-3 had the same weight percentage compared to M-2, which was unusual as it was expected to have a higher percentage compared to M-2. M-4 had the highest weight percentage, with M-5 being slightly lower.
Each sample showed decent thermal stability until around 400°C, which is where a significant decrease in weight percentage occurred. The difference in weight differences could be explained by the reduction of low molecular weight volatiles for each pretreatment. This would cause more of the original weight to be the large molecular weight components of the asphaltene, improving thermal stability.

Rheology

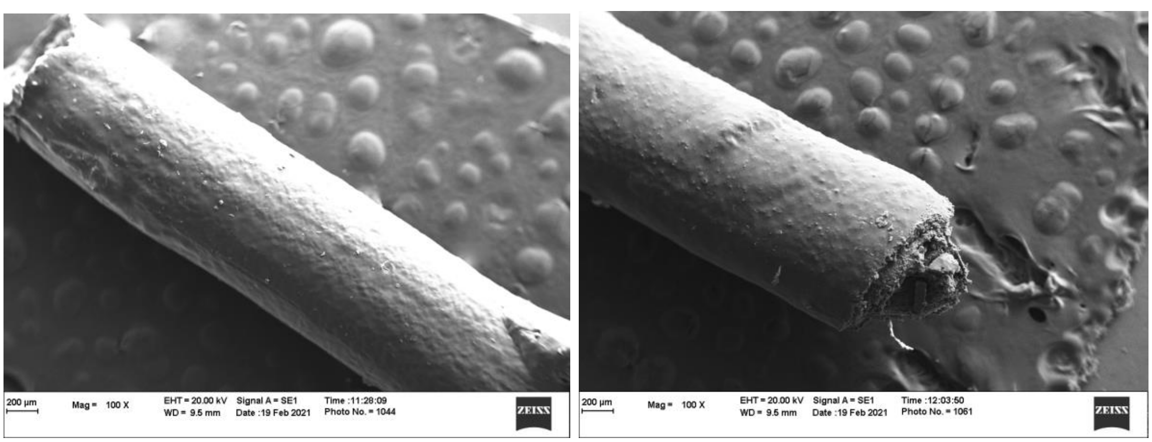
Rheology for asphaltene pretreated with methods 3, 4, and 5 could not be performed because the asphaltene retained its powdered form at the highest temperature, which was not safe for the rheometer. This was, in theory, due to the asphaltene crosslinking, as supported by the 1H-NMR study of the three materials. Rheology was performed for the asphaltene as received and the asphaltene pretreated with methods 1 and 2.
The strain sweep test showed that the linear regions for both G' of the asphaltene as received occurred between 0.1% strain and 1% strain. Therefore, the strain of 0.5% was selected for the temperature sweep tests of the asphaltene samples in order to keep the test consistent for all three materials.
Pretreatment methods 1 and 2 increased the G' of the asphaltene relative to the G' of asphaltene as received for temperatures above 120°C, which indicated the successful

removal of low molecular weight volatiles during the first air pretreatment step. The G' increased as the temperature decreased for each of the samples, as was expected. At 250°C, the viscosities of all three asphaltene samples were similar. As the temperature was reduced, the viscosities of all three samples increased. The viscosity of the asphaltene pretreated with method 1 increased more than the other asphaltene samples. The viscosity of the asphaltene pretreated with method 1 remained constant below 210°C, whereas the viscosities of the asphaltene as received and the asphaltene pretreated with method 2 increased until 160°C. The lower temperature at which the viscosity became constant for asphaltene pretreated with method 2 suggested that the oxygen compounds produced by the hotter air treatment step are primarily of low molecular weight. Below 160°C, the viscosities of the three samples were similar and remained constant for the remainder of the temperature range tested. 150°C was the temperature chosen for extrusion because it was within the linear regions of the viscosity and G' for asphaltene as received and pretreated with methods 1 and 2.

<u>b) Extrusion</u>

Due to the results of the rheological study, only three samples were used with the single screw extruder: Asphaltene as received, M-1 asphaltene, and M-2 asphaltene. The remaining three samples could not be adequately extruded.

The three different samples produced using the single screw extruder were uniformed filaments. Each filament had a diameter of 800 μm, which was determined using the SEM. This diameter was uniform throughout the filaments that were analyzed. An attempt to extrude a M-1 sample resulted in a filament that was rough and powdery. This was also confirmed using the SEM.



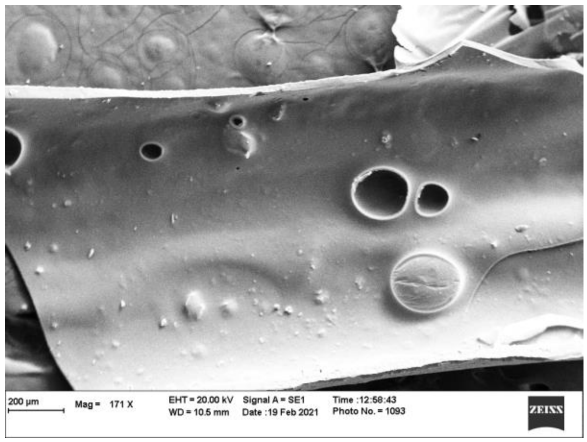
M-1 Asphaltene Extruded Fiber M-2 Asphaltene Extruded Fiber

Figure 1 – Asphaltene Samples extruded

<u>c) Stabilization and Carbonization</u>

The three samples that were extruded, asphaltene as received, M-1, and M-2 asphaltene, were then carbonized. Asphaltene as received, did not retain its fibrous morphology. Both M-1 and M-2 were better at retaining their original morphology compared to the asphaltene as received.

For both M-1 and M-2, the carbonized material appeared like a flattened fiber. The surface of each sample had pores. Due to both the flattened nature and the presence of pore, it is believed that the extruded asphaltene still contained low molecular weight volatiles. During the carbonization, the volatiles were released, causing the pores to form and for the fiber to deflate.



M-2 Asphaltene Carbonized Fiber

Figure 2- Carbonized Asphaltene samples

Project Metrics

The first metric of this project was the pretreatment of the asphaltene, which had two subgoals: chemical separation of asphaltene and thermal treatment of asphaltene. A majority of the metric was achieved. With the chemical separation subgoal, while there was no chemical separation, an analysis of the individual elements making up the asphaltene was analyzed using EDS. This not only provided insight into the asphaltene as received but also with the different pretreated samples using the thermal treatment.

The second metric of this project was the fabrication of carbon fibers, which had three different subgoals: fabrication of melt-spun asphaltene fibers, stabilization and carbonization of asphaltene fibers, and characterization of carbon fibers. All of these subgoals were successfully performed, though more experiments are needed in order to refine the results. The asphaltene as received, and two of the pretreated asphaltene were able to be extruded using a single screw extruder to form the asphaltene fiber precursor. These fibers were then carbonized. While the asphaltene as received fiber did not produce carbon fiber, the remaining two samples produced a material similar to carbon fiber. Lastly, visual analysis was performed on the samples to determine their morphology through additional characterization methods will be performed in the near future.

The last metric of this project was the identification of partners for graphitization and scale-up purposes for the phase II portion of the project.

One company was identified for phase II: Toray Carbon Fibers America, a Carbon Fiber production plant located in Decatur, Alabama. They have an R&D department, and it is mentioned on their webpage that 50% of R&D expenses will be allocated to R&D related to Green Innovation and 20% to Life Innovation.

Project Success Metrics (Metrics to be identified by Applicant)			
Metric	**Project Target**	**Commercialization / Implementation Target**	**Comments (as needed)**
Chemical Species Content Tracking	*During this Phase, the team will understand the sulfur and other chemical content at each step of the manufacturing process*		
Production of micron-sized fibers (targeted size 7-9 micros)	*During this Phase, the team will produce micron sized fibers*		
Modulus	*<100 Gpa*	*>250 Gpa*	*We anticipate obtaining fibers with low modulus since the graphitization porcess will not be considered during Phase 1*
Tensile strength	*<1000 Mpa*	*>3000 Mpa*	*We anticipate obtaining fibers with low Tensile Strength since the graphitization process will not be considered during Phase 1*
Flowsheet for CF Process	*1*	*1*	*Project flowsheet will differ from commercial flowsheet*

The metrics initially set out were ambitious and as the research progressed, it became apparent that additional time would be required to meet the metrics listed above. With a greater understanding now of the behavior of asphaltenes and their composition, these metrics are realistic targets for Phase II.

F. KEY LEARNINGS

Please provide a narrative that discusses the key learnings from the project.

- Describe the project learnings and importance of those learnings within the project scope. Use milestones as headings, if appropriate.
- Discuss the broader impacts of the learnings to the industry and beyond; this may include changes to regulations, policies, and approval and permitting processes

The major findings of this project are from the characterization that was done on the pretreated asphaltene. Through the characterization that was done on the different pretreated materials, specifically through using the EDS, ^{1}H-NMR, and rheometer. With the EDS and ^{1}H-NMR, it was determined that certain pretreatment methods caused too much crosslinking within asphaltene, which is an undesirable outcome. This crosslinking was later confirmed with the rheometer as certain samples did not melt, which corresponded to the samples that showed too much crosslinking with the prior two characterization methods.

A second major finding was the importance of removing the low molecular weight volatiles. These volatiles did not cause any noticeable impact during the extrusion process, but during the carbonization process, it could be seen that the asphaltene as received fibers did not resemble its original morphology. The two different pretreated asphaltenes carbon fibers more closely resembled their original morphology though it was still seen that pore formed where gasses likely escaped from. As this project moves forward, increased analysis of the volatile removal process will be analyzed.

A broader impact of this project shows the potential of using asphaltene as a carbon fiber precursor. Currently, asphaltene is removed towards the beginning of the oil refinery process in order to prevent it from clogging the pipeline [1]. Outside of asphaltene's being a part of asphalt, there is little use for the material. Having the capability of using this material as an alternative source of carbon fiber will create a new value-added stream for the refinery process and make the refinery process a more sustainable process by using more of the raw materials.

G. OUTCOMES AND IMPACTS

Please provide a narrative outlining the project's outcomes. Please use sub-headings as appropriate.

- **Project Outcomes and Impacts:** Describe how the outcomes of the project have impacted the technology or knowledge gap identified.
- **Clean Energy Metrics:** Describe how the project outcomes impact the Clean Energy Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- **Program Specific Metrics:** Describe how the project outcomes impact the Program Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- **Project Outputs:** List of all obtained patents, published books, journal articles, conference presentations, student theses, etc., based on work conducted during the project. As appropriate, include attachments.

<u>Project outcomes and Impacts</u>
This project showed a way to convert asphaltene into carbon fibers using the thermal treatment and single screw extrusion.

<u>Clean Resources Metrics</u>

Clean Resources Metrics (Select the appropriate metrics from the drop down list)			
Metric	**Project Target**	**Commercialization / Implementation Target**	**Comments (as needed)**
$ Future Investment			Anticipate significant capital to be required for commercialization .
$ in Clean Technology	$50,000		
# of Publications	**1**	**0**	Anticipate one publication arising from success in Phase 1 of the Grand Challenge.
# Students (Msc., PhD, Postdoc)	**1**	**0**	One posdoctoral fellow will be involved in Phase 1
# Patents filed	**1**	**0**	Anticipate one patents arising from success in Phase 1 of the Grand Challenge.
Partnership agreements / MOUs?	Yes	Yes	Anticipate two MOUs arising from success in this phase and other Grand Challenge Phases.
# New products/services created	0	1	Anticipate one product arising from success in other Grand Challenge Phases.
# New Spin-Off Companies created	0	1	Anticipate one spin off arising from success in other Grand Challenge Phases.

Currently, there have been no publications nor conference presentations on this material. A journal article is currently being written for publication, and the research that is being done will be incorporated into the thesis of John Hinkle III, a Ph.D. candidate from Auburn University. No patents have been filed yet but could be anticipated in Phase II. One student participated in the project.

Program Specific Metrics

Program Specific Metrics (Select the appropriate program metrics from the drop down list)			
Metric	**Project Target**	**Commercialization / Implementation Target**	**Comments (as needed)**
# of End Users participating	This project will have a composites manufacturer participating	For the commercial implementation, we will require multiple end users to validate the performance of the fibers	Towards the conclusion of Phase I, the research team will approach carbon fibers producers in the United States
Unique product/process	1	1	
# commercial BBC products	0	1	

Research conducted in this Phase I project has advanced the technology towards developing a unique product and process.

H. BENEFITS

Please provide a narrative outline the project's benefits. Please use the subheadings of Economic, Environmental, Social and Building Innovation Capacity.

- **Economic:** Describe the project's economic benefits such as job creation, sales, improved efficiencies, development of new commercial opportunities or economic sectors, attraction of new investment, and increased exports.
- **Environmental:** Describe the project's contribution to reducing GHG emissions (direct or indirect) and improving environmental systems (atmospheric, terrestrial, aquatic, biotic, etc.) compared to the industry benchmark. Discuss benefits, impacts and/or trade-offs.
- **Social:** Describe the project's social benefits such as augmentation of recreational value, safeguarded investments, strengthened stakeholder involvement, and entrepreneurship opportunities of value for the province.
- **Building Innovation Capacity:** Describe the project's contribution to the training of highly qualified and skilled personnel (HQSP) in Alberta, their retention, and the attraction of HQSP from outside the province. Discuss the research infrastructure used or developed to complete the project.

Economic

There are a number of potential economic benefits of this project. The most immediate benefit of the project is adding an additional value-added stream due to the new utilization of the asphaltene. As research increases in this field, there is potential for a scaled-up version of the novel carbon fiber development. This scaled-up version would require a number of different positions, such as chemical engineers for plant maintenance, operational management for plant efficiency, and polymer engineers for developing composites from the produced carbon fiber, to name a few.

Environmental

This project has a little direct beneficial impact on the environment. One benefit is increasing the utilization efficiency of crude oil. While the usage of fossil fuels negatively impacts the environment, by improving efficiency, crude oil can be used more for the same environmental impact. In addition, the low molecular volatiles that is released during the pretreatment and carbonization could potentially be hazardous if not properly handled. Another benefit is the avoided emissions by not converting asphaltenes to fuels and subsequent combustion.

Social

This project's main social impact would be the increase of entrepreneurship opportunities of value for the province. By utilizing a resource that is developed in the province of Alberta, new companies could form to convert the asphaltene into carbon fiber as their primary source of outputs. This would, as mentioned, create new jobs but would also increase the amount of trade between the companies that remove the asphaltene from crude oil and the companies that utilize it.

Building Innovation Capacity

Further development into this field of research and development of an industry based on this research will require the recruitment of a number of HQSP in Alberta. As mentioned, a number of different positions are required for the successful execution of carbon fiber development. These recruits would need several higher education degrees. This would cause an increase in retention of HQSP who are from Alberta and an influx of HQSP from outside of the province. The research infrastructure used in this research included a number of different characterization equipment and three other pieces of equipment for the actual development of the carbon fiber.

I. RECOMMENDATIONS AND NEXT STEPS

Please provide a narrative outlining the next steps and recommendations for further development of the technology developed or knowledge generated from this project. If appropriate, include a description of potential follow-up projects. Please consider the following in the narrative:

- Describe the long-term plan for commercialization of the technology developed or implementation of the knowledge generated.
- Based on the project learnings, describe the related actions to be undertaken over the next two years to continue advancing the innovation.
- Describe the potential partnerships being developed to advance the development and learnings from this project.

In order to develop the asphaltene into carbon fiber for commercialization purposes, more research on the laboratory scale is needed. Over the next two years, further research into the thermal pretreatment and specifically the removal of volatiles will be looked into as it showed great potential during the initial investigation. In addition to this, after the carbon fiber is developed, research into the mechanical properties and electrochemical properties will be looked at in order to determine more specific applications for commercialization.

J. KNOWLEDGE DISSEMINATION

Please provide a narrative outlining how the knowledge gained from the project was or will be disseminated and the impact it may have on the industry.

The knowledge gained from this project will be disseminated through a number of methods. Currently, a paper is being written on the work that has already been performed, and this work will be included in a Ph.D. thesis. In addition to these two works, this research will also be presented at a number of conferences in the future as well as additional papers will likely be written as this research continues.

K. CONCLUSIONS

Please provide a narrative outlining the project conclusions.

- Ensure this summarizes the project objective, key components, results, learnings, outcomes, benefits and next steps.

This project's purpose was to utilize asphaltene to develop carbon fibers for commercialization purposes. To do so, the asphaltene was pretreated and extruded to form the asphaltene fibers. These fibers were then carbonized to produce the asphaltene-based carbon fibers. While these fibers showed non-desirable traits, it was an improvement in an attempt to carbonize asphaltene fibers that had not been pretreated prior. This attempt shows that asphaltene can be a potentially untapped source of carbon fiber. As this research moves forward, the carbon fibers that are produced from the asphaltene should improve, providing new possibilities for commercialization.

References

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