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 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 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.

CLEAN RESOURCES FINAL PUBLIC REPORT TEMPLATE

1. PROJECT INFORMATION:

Project Title:	**Carbon Fiber Grand Challenge – Phase 1**
Alberta Innovates Project Number:	CFGC G2020000343
Submission Date:	April 28th, 2020
Total Project Cost:	$69,300
Alberta Innovates Funding:	$49,500
AI Project Advisor:	Murray Gray

2. APPLICANT INFORMATION:

Applicant (Organization):	**Zetetic Associates Ltd.**
Address:	6213 34th Ave., Camrose AB, T4V 3X3
Applicant Representative Name:	Tony Hladun
Title:	Director
Phone Number:	780-672-5067
Email:	hladun@cable-lynx.net

3. PROJECT PARTNERS

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

RESPOND BELOW

Zetetic Associates Ltd. was the project manager and was also responsible for a cost analysis of the manufacture of carbon fibers derived from Alberta asphaltenes. Clemson University conducted experimental research on Alberta asphaltenes utilizing extensive carbon fiber research infrastructure at its Center for Advanced Engineering of Fibers and Films (CAEFF).

A. EXECUTIVE SUMMARY

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

RESPOND BELOW

The objective of this project was to investigate the viability of utilizing Alberta-based asphaltenes to produce high-value carbon fibers. Clemson University through its Center for Advanced Engineering of Fibers and Films produced carbon fibers from asphaltene samples provided by Alberta Innovates. Zetetic associates conducted a preliminary process economic analysis that indicated carbon fiber could be produced from asphaltenes at around US$6/lb.

This first phase of the Grand Challenge investigated Alberta asphaltene samples A and C (also referred to as S1 and L2, respectively) that were respectively solid and viscous (liquid) at room temperature. L2 could not be drawn into fibers in as-received state, and further heat-treatment produced under 20 wt% yield, so this sample was not investigated much in this Phase I study. In contrast, as-received S1 (sample A) could be melt-spun into asphaltene fibers. However, these fibers could not be stabilized as the fibers tended to stick during the oxidation process, so carbon fibers could not be obtained initially. Subsequently, this asphaltene sample was heat-treated using a proprietary process while achieving a high yield of about 70 wt%. The heat-treated asphaltene could also be melt-spun and, very importantly, could be oxidatively stabilized. Subsequently, **carbon fibers were successfully produced**.

Carbon fibers were characterized for their microstructure. Scanning electron micrographs reveal a mildly graphitic texture particularly at higher carbonization temperature. **Raman spectroscopy also revealed a similar trend in that the graphitic G-peak increased with increasing carbonization temperature relative to the D-peak (disordered). The tensile properties of individual filaments were measured, and some of the best filament samples displayed tensile strength and apparent modulus as high as 1.25 GPa and 75 GPa, respectively.** Properties of these preliminary carbon fibers, obtained within a duration of a four months, could not match those obtained from expensive, commercial PAN precursors. However, the results are encouraging, and optimization of various process conditions is warranted in Phase II Grand Challenge. As the process steps are further refined, a detailed economic analysis can be done to identify further cost reductions, below US $6/lb.

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.

RESPOND BELOW

To diversify its petroleum industry, Alberta through Alberta Innovates initiated an undertaking referred to as Bitumen Beyond Combustion. One of the areas identified was to make carbon fibers from asphaltenes, which are a byproduct of oil upgrading. Alberta Innovates issued the Carbon Fiber Grand Challenge to invite and sponsor research in this area.

Previously, carbon fibers have been successfully produced from petroleum pitch. Recent advances in upgrading and sulfur/contaminant removal from oil sands suggests that a lower-cost and higher strength carbon fibers could be produced from asphaltenes. A review of the literature reveals that a patent has been issued to Honeywell Federal Manufacturing and Technologies LLC (US9580839B2), but there is no evidence that it has been used to obtain carbon fibers with commercially useful properties. Consequently, several knowledge gaps exist.

First, a major technology gap exists currently is that there is no established process to spin asphaltenes into precursor fibers nor conversion to carbon fibers using a commercially relevant process. Also, there is no baseline study on CF properties.

Second, sulphur and other impurities deteriorate the quality of CFs because such impurities tunnel out from the fibers and create holes that destroy CF strength. Currently, there is no data to quantify the maximum permissible/ threshold levels (of impurities), temperature at which these impurities off-gas, and the extent of strength reduction. Also, the desirable chemical structure of processed asphaltene to directly produce carbon fibers is not established.

Finally, crosslinking or “oxidative stabilization” of as-spun precursor fibers is the most critical step in conversion of any compound to carbon fibers. PAN-based commercial CFs do this successfully because PAN-precursor fibers are wet-spun from a PAN solution (because PAN cannot be melted). However, once PAN fibers have been produced, they are easily thermally cross-linked/stabilized because PAN does not melt. That will not be the case for asphaltene-based CFs because asphaltene fibers will have to be melt-spun. However, to ensure short enough stabilization time (long times mean high costs and poor process economics), the absolute stabilization temperature must be high enough because reaction rates increase exponentially with T (Arrhenius law). But too high a softening point means spinning is difficult because high T leads to degradation of hydrocarbons. Thus, an optimal softening point range must be determined for modified asphaltenes, which is currently unknown.

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.

Successful production of CFs is only possible when the precursor fibers can be adequately cross-linked, also referred to as “stabilized”, so that such fibers can be carbonized at temperatures of about 1000ºC. This step involves crosslinking of the molecules within the precursor fibers such so that they will not soften/stick/melt as the temperature exceeds the original softening point of precursor, otherwise chunks of useless carbon is produced. Stabilization is accomplished by oxidative cross-linking of as-spun fibers in air at elevated temperatures (200-300ºC) to generate chemical bonds between carbon atoms from adjoining molecules. To minimize process time and maximize extent of crosslinking, higher stabilization temperatures are desirable because reaction rates increase exponentially with temperature. However, this stabilization temperature MUST remain below the softening point (SP) of the precursor to prevent fiber adhesion. Thus, precursors with inherently high SP are desired. However, excessively high SP necessitates a higher fiber spinning temperature, which is not desirable because a high temperature also causes degradation of the hydrocarbon precursor leading to generation of volatiles/bubbles (defects) that destroys CF strength. Therefore, the major objectives of this Phase I study were to: (i) identify a composition-stabilization regime (temperature and time); (ii) analyze resulting carbon fibers for their microstructure and tensile properties.

The metrics were:

(i) Carbon fibers could actually be produced using Alberta-based asphaltenes; and

(ii) Quality of carbon fibers was adequate so that their graphitic microstructure could be characterized (SEM, X-ray diffraction, and Raman spectroscopy) and tensile modulus and strength measured.

D. METHODOLOGY

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

RESPOND BELOW

Methodology:

The team consisted of Zetetic Associates (Alberta, CA) and Clemson University (South Carolina, USA). Zetetic is an Alberta based consulting company headed by Mr. Anthony Hladun, who has over 40 years of industrial experience in project management and engineering consulting, provided project management services and conducted process economics analysis. Clemson University team was headed by Prof. Amod Ogale, Director of Center for Advanced Engineering Fibers and Films (CAEFF) and Dow Chemical Professor of Chemical Engineering. Prof. Ogale has 34 years of research experience at Clemson working with carbon fibers and their composites. He was assisted by one post-doctoral associate, one PhD student, and one undergraduate research assistant, all working on the project on a part-time basis.

Facilities:

Clemson team used the following custom-designed processing equipment and sophisticated characterization instruments for analyzing/processing materials. (i) Processibility: Mettler-Toldeo softening point (SP) device for to analyze flow behavior of asphaltenes; (ii) Fiber Spinning: Batch and continuous units rated to 400˚C and 100 atm pressure; (iii) oxidative stabilization ovens, automated to provide a wide range of heating rates, (iv) carbonization furnaces capable of heating up to 2500˚C; (iv) Hitachi SEM microscopes, Raman spectrometer; Rigaku X-ray diffraction unit; and (v) tensile testing capability to measure modulus and strength of single carbon fibers.

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.

RESPOND BELOW

Materials: Alberta Asphaltenes

Sample A (also referred to as S1) was provided by Alebrta Innovate at the beginning of the project,. This sample was a solid at 25˚C and had been obtained without much further refinement of asphaltenes, so it contained relatively high amounts of sulphur and other impurities. Therefore, sample A was the focus of this study with the goal of ultimately producing low cost carbon fibers.

Asphaltene sample A (S1) was measured to have a Mettler-Toledo softening point of ca 150˚C. The as-received A asphaltene was successfully melt-spun using a batch spinning unit, as illustrated in Figure 1(a). However, these as-spun fibers could not be oxidatively stabilized even over an impractically long duration of 3 days. Consequently, the resulting fibers stuck together, as shown in Fig. 1(b), which is unacceptable for production of carbon fibers.

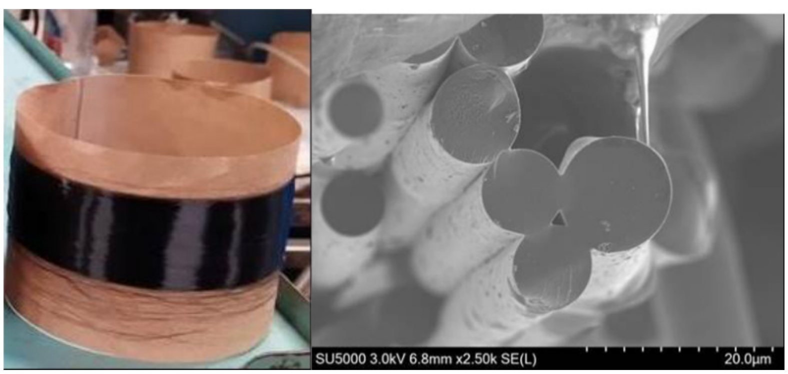

Figure 1. (a) Melt-spun asphaltene fibers produced from as-received sample A (also called S1); and (b) Asphaltene fibers stuck together during oxidative stabilization.

Heat-treated A (S1) Fiber-Spinning

To achieve oxidative stabilization within fibers, the reaction temperature needed to be increased. However, this can also lead to sticking of fibers for a given softening point (SP). Therefore, it is imperative that the asphaltene sample have higher SP to begin with, which was achieved using proprietary conditions. This heat-treated sample, referred as "HT-A", was successfully melt-spun using CAEFF-Clemson's custom-designed batch-spinning unit. These fibers could be oxidatively stabilized to prevent fibers fusion and yet attain sufficient crosslinking within the asphaltene that these stabilized fibers could be successfully carbonized using various proprietary heat-treatment conditions. Thus, carbon fibers as fine as 15-20 µm were produced, **thus successfully achieving Metric C(i) [*as specified in Section in Section C*].**

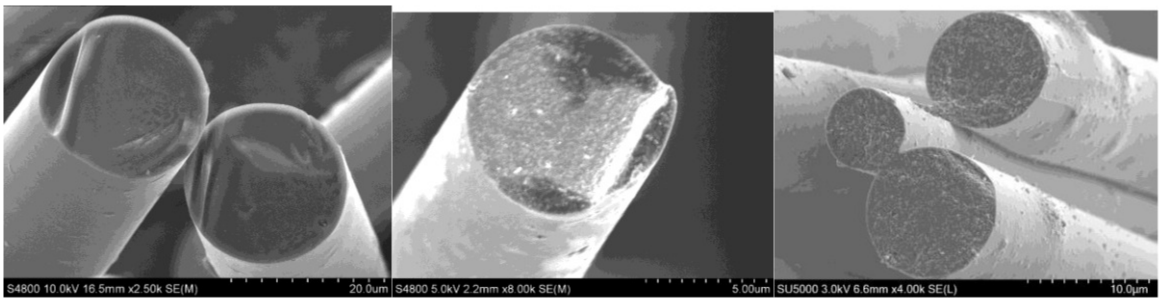

Figure 2. Scanning electron micrographs (SEM) of carbon fibers obtained from heat-treated asphaltene produced from sample A (also S1) that was provided by Alberta Innovate. Carbon fibers produced at increasing temperatures (left to right) showing development of graphitic texture.

Sample C (also called sample L2)

The low-sulphur sample C (L2) received from Alberta Innovate was a viscous liquid at 25˚C, i.e., not solid. Consequently, it was not possible to *melt-spin* and draw filaments from this grade and maintain them as individual filaments. It was inferred from Field Upgrading presentation at the Grand Challenge Symposium that the asphaltene molecules may be getting broken down during de-sulphurization process leading to a low softening point. Therefore, significant build-up of molecular weight is needed before this sample can become a potential carbon fiber precursor. Preliminary heat-treatment experiments conducted during this project (using proprietary conditions) reveal that a high softening point may be achievable at a yield of about 20 wt%. Further, experiments are recommended to enhance the heat treatment conditions to obtain a high-quality and high-yield precursor. This needs to be accomplished in Phase II of the Grand Challenge in collaboration with partners that will be identified before submission of Phase II proposal.

Microstructural Analysis

To characterize the microstructure of carbon fibers produced from Alberta asphaltenes, Raman spectroscopy was conducted using a Ramascope-1 unit. Using an exposure time of 15 s and a laser wavelength of 785 nm, spectra were obtained for various carbon fibers. Two characteristic spectra are illustrated below in Figure 3 for lowest (left) and highest carbonization temperatures. The spectrum on the right clearly shows the prominent graphitic G-peak develop at 1582 cm^{-1}.

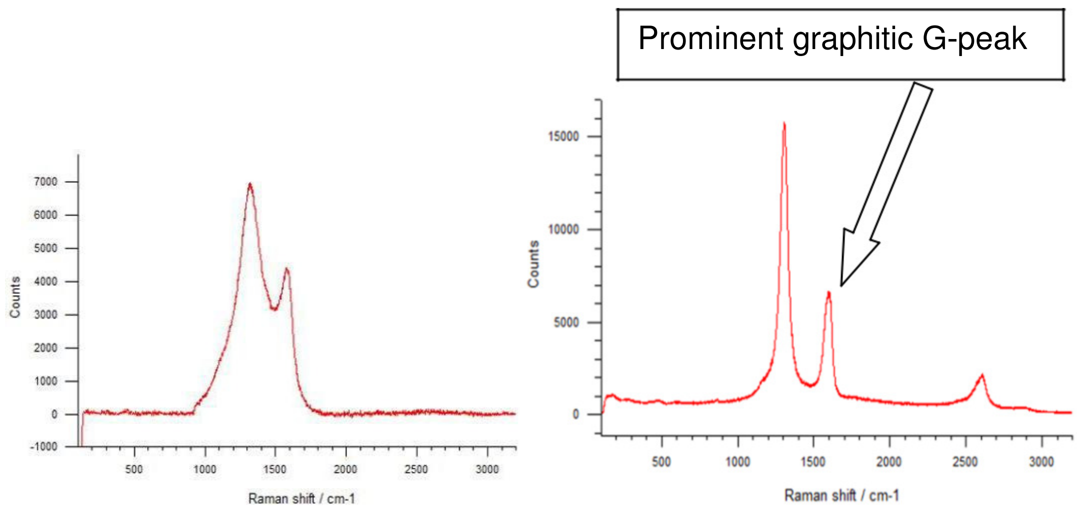

Figure 3. Raman spectra for carbon fibers produced from HT-A asphaltene at low (left) and high (right) carbonization temperatures using proprietary process conditions.

In contrast, the peak at 1312 cm-1 is for the disordered phase of carbon. The location of these D- and G-peaks (as well as higher order D' and G' peaks), is summarized below in Table 1. An increase in the area ratio of G-to-D peaks, from 0.23 to 0.34, indicates the development of better carbon formation and enhanced graphitic content with increasing carbonization temperature.

Table 1. Summary of Raman spectroscopy analysis of carbon fibers obtained at low and high treatment temperatures

Carbonization temperature	D peak shift (cm^{-1})	G peak shift (cm^{-1})	D' peak shift (cm^{-1})	G' peak shift (cm^{-1})	A_G/A_D ratio
Low	1312	1583	No peak	No peak	0.23
High	1312	1582	1612	2615	0.34

Wide angle x-ray diffraction was conducted on various carbon fibers using a Rigaku diffractometer. Carbon fibers heat treated at lower temperature displayed the (0 0 2) peak, i.e., that associated with carbon layer planes, at a two-theta angle of 21.5˚. In contrast, for carbon fibers obtained at high carbonization temperature, the two-theta peak shifted to a higher a value of 26.0˚ showing better graphitic formation.

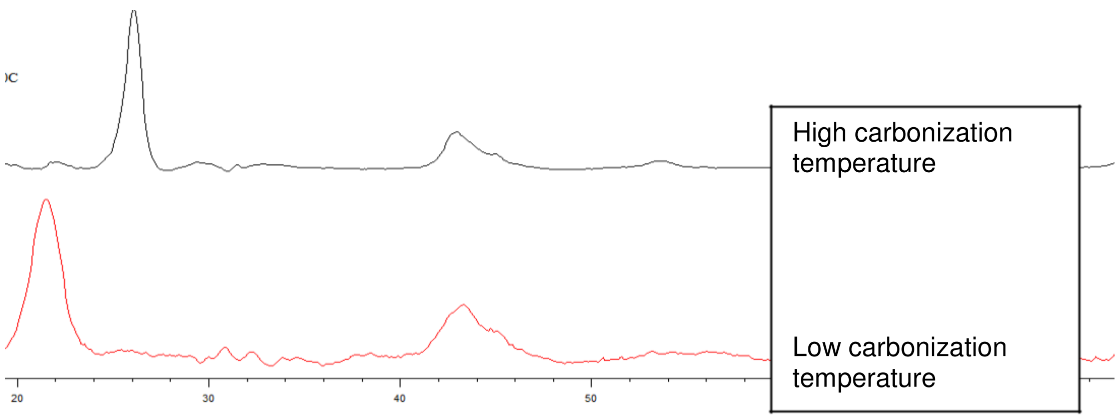

Figure 4. Wide angle diffraction spectra showing various peaks as a function of 2-theta angles for carbon fibers produced at low (left) and high (right) carbonization temperatures.

Tensile Properties

Tensile strength and apparent modulus were measured for individual carbon fibers using expertise developed at CAEFF-Clemson labs. Average values were obtained by testing over ten replicates. Table 2 displays typical diameter, modulus and strength values for a set of carbon fibers obtained using a low heat treatment temperature.

Table 2. Carbon fiber diameter, apparent modulus and tensile strength obtained from single filament testing using a gage length of 10 mm.

Specimen #	**Fiber diameter (μm)**	**Tensile Strength (GPa)**	**Apparent Modulus (GPa)**
1	24	0.65	52
2	15	1.06	64
3	16	1.05	52
4	19	0.76	39
5	16	0.61	55
6	14	1.00	75
7	16	1.25	51
8	24	0.27	27
9	23	0.41	28
10	16	0.53	26
12	15	0.59	27
Avg	**18**	**0.74**	**45.0**
StdDev	**4**	**0.31**	**16.5**

For carbon fibers nominally 15-20 µm in diameter, the **average** tensile strength was measured at 0.74 GPa (740 MPa) and the apparent tensile modulus at 45 GPa. **Individual filament samples displayed strengths and apparent moduli as high 1.25 GPa and 75 GPa, respectively.** System compliance correction could not be performed due to the limited time available to conduct this Phase 1 project, but prior studies on other precursors indicate the corrected compliance could exceed 100 GPa. These tensile properties are for carbon fibers produced from asphaltene samples containing a significantly high Sulphur/impurities. Thus, carbon fibers produced at a high carbonization temperature led to a lower strength of about 260 MPa, as expected. This is because impurities tunnel out of the fibers during carbonization step and produce defects that reduce tensile strength. However, it is also noted that the carbon fibers produced at the highest carbonization temperature displayed a high electrical conductivity of 1.25 S/m, using a 4-point standard method for measuring single filament properties. This translates to an ultrahigh thermal conductivity of 100 W/m.K, which is about TEN times that of carbon fibers produced from conventional PAN precursors.

In summary, although properties similar to those of high-cost commercial fibers (obtained from PAN) have not yet been obtained from this Phase I project (that provided limited funding and time), results from this project have clearly established that carbon fibers can be produced from Alberta asphaltenes, **meeting Metric (i) as specified in Section C**. Further, although precursor quality or process conditions have not yet been optimized in this Phase I study, carbon fibers thus produced displayed reasonably good graphitic layer formation and properties, **meeting Metric (ii), Section C.**

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

RESPOND BELOW

As discussed earlier, it was learned that carbon fibers can be produced from Alberta asphaltenes. Although properties similar to those of high-cost commercial fibers (obtained from PAN) have not yet been obtained from this Phase I project (that provided limited funding and time), these asphaltene-derived carbon fibers possessed tensile strength and apparent modulus as high as 1.25 GPa and 75 GPa, respectively.

Further, enhancements to properties will have to be accomplished by development of **low-impurity, high quality precursors** coupled with **optimized process conditions to provide high yields**. Thus, Phase II study will need to develop more sophisticated reactive extraction techniques. This will provide a positive impact on the extensive industrial infrastructure in Alberta for enhanced utilization of oil-sands and resulting asphaltenes.

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,

Project Outcomes and Impact:

This project has established the proof-of-concept that Alberta asphaltenes can be used to produce carbon fibers. The potential economic impact is that the vast oil sands resource that Alberta province possesses can be used for an ultrahigh value product – carbon fibers.

Program Specific Metrics:

Both metrics specified in the project were satisfactorily met.

(i) Experimental results (see Figure 2, Section E. RESULTS) have proven that actual carbon fibers were produced from Alberta asphaltenes; and

(ii) Carbon fibers thus produced displayed adequate graphitic texture (Figure 3 and 4) and tensile strength and modulus (Table 1).

Project Outputs:

Salient results from the project were presented at the Grand Challenge Phase 1 Symposium November 5, 2020.

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:

As discussed in Section E. Project Results, Clemson team has demonstrated the feasibility of actually producing carbon fibers from Alberta-based asphaltenes. The Zetetic team has done preliminary process economic analysis to estimate that carbon fibers can be produced from Alberta asphaltenes at around US$6/lb.

Environmental:

This project demonstrates the positive impact of utilization of asphaltenes that are generated as undesired/ low-value by-products from oil sands. Conversion of these asphaltenes to carbon fibers has the tremendous potential of use in low-weight high-performance composites that be utilized for environmentally desirable application such as reduced weight of cars, and enhanced quality of industrial products such as concrete and steel cables.

Building Innovation Capacity:

This project indicates the potential for Alberta to utilize its natural resources (oil sands) to develop a low-cost precursor for the production of high value products, viz. carbon fibers

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.

RESPOND BELOW

For future studies in Phase II, following strategy is recommended:

(i) As-received, low-cost asphaltenes need to be further investigated to determine optimum spinning and carbonization conditions to enhance carbon fibers properties (strength and modulus);

(ii) For desulphurized asphaltene samples need to be further analyzed by suitable heat treatment to enhance it molecular weight/structure and increase the softening point. This must be done to improve its fiber spinning capability as well as subsequent stabilization and carbonization conditions.

Preliminary discussions have been done with Field Upgrading LLC for further refinement of their process to obtain low-impurity asphaltenes with increased softening temperature. Other potential industrial and research partners include CanMet, McGill.

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.

RESPOND BELOW

Results from the project were presented at the Grand Challenge Phase 1 Symposium November 5, 2020. The symposium was attended by carbon fiber manufacturers, composite material users and researchers from university and research labs.

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.

RESPOND BELOW

The objective of this project was to investigate the viability of utilizing Alberta-based asphaltenes to produce high-value carbon fibers. Clemson University through its Center for Advanced Engineering of Fibers and Films produced carbon fibers from asphaltene samples provided by Alberta Innovates and Zetetic associates conducted a preliminary process economic analysis.

Major components of the study included actual melt-spinning of asphaltenes followed by appropriate heat treatments to obtain carbon fibers. As-received A (also labeled S1) could be melt-spun into asphaltene fibers but could not be stabilized (fibers tended to stick during the oxidation process), so carbon fibers could not be obtained initially. Subsequently, this asphaltene sample was heat-treated using a proprietary process while achieving a high yield of about 70 wt%. The heat-treated asphaltene could also be melt-spun and, very importantly, oxidatively stabilized to successfully produce carbon fibers.

Scanning electron microscopy results revealed a mildly graphitic texture particularly at higher carbonization temperature, which was consistent with Raman spectra that also revealed that the graphitic G-peak increased with increasing carbonization temperature (relative to the disordered D-peak). Individual carbon fibers could be handled nicely and some of the best carbon fiber filaments displayed tensile strength and apparent modulus as high as 1.25 GPa and 75 GPa, respectively. The outcome of a preliminary process economic analysis conducted by Zetetic Associates indicates the potential of carbon fibers being produced from such asphaltenes at around US$6/lb.

Properties of these preliminary carbon fibers, obtained within a duration of four months, could not match those obtained from expensive, commercial PAN precursors. However, the results are encouraging and point to the environmental and economic benefits of low cost asphaltenes. Further development and optimization of various precursors and process conditions is warranted as next steps in Phase II Grand Challenge.