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:	**Improving mesophase generation for higher performance carbon fiber - Bitumen derived**
Alberta Innovates Project Number:	212201667
Submission Date:	March 8th, 2023
Total Project Cost:	$596,854
Alberta Innovates Funding:	$144,143
AI Project Advisor:	Paolo Bomben

2. APPLICANT INFORMATION:

Applicant (Organization):	**Suncor Energy Services Inc.**
Address:	150 6 Ave SW, Calgary, AB T2P 3E3
Applicant Representative Name:	Todd Pugsley
Title:	Director, Technology Development
Phone Number:	(403) 875-4674 (Cell), (403) 296-8062 (office)
Email:	TPugsley@suncor.com

3. PROJECT PARTNERS

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

RESPOND BELOW

Alberta Innovates and Suncor were only entities that provided funding support for this project. No project partners for this project.

A. EXECUTIVE SUMMARY

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

RESPOND BELOW

Suncor has advanced learnings of converting asphaltenes to general purpose and higher strength general purpose carbon fiber. The next stage in the development of asphaltenes feedstocks to higher performance carbon fiber involves improving the ability to generate high mesophase content carbon fiber precursor. Suncor has a couple promising avenues to advance the improvement of carbon fiber properties of Suncor derived feedstocks. Building upon previous learnings, for this stage of development, researcher lab scale facilities continued to be leveraged to analyze, research and test the steps outlined in the project plan. Detailed proposals from each researcher were received and evaluated to inform the project scope. Suncor has successfully used this approach collaborating with external researchers in the past to advance technology development. At the end of this project, the team has further advanced the technology to convert bitumen derived feedstock to a precursor suitable for carbon fiber making.

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

Sector Introduction:

Carbon fiber (CF) from bitumen feedstock was identified as one of the four highest value opportunities for economic diversification of the oil sands in the 2018 Bitumen Beyond Combustion (BBC) Phase 2 report prepared for Alberta Innovates by Stantec Consulting Ltd. CF is widely touted to become the material of the 21st century, but if CF production is to grow exponentially, supply cost will need to be reduced and it will need to integrate and replace major global commodities such as steel, cement, and wood-based products.

CF production can be broken out into three main areas – precursor feedstock, spinning and carbonization, and end-product manufacturing. Considering the growth potential and relative early stage of development of the CF industry, there is a tremendous opportunity to work towards oil sands-based feedstocks becoming a major component in the evolving CF industry as precursor feedstock. Additional aspects of CF production, such as spinning and end-product manufacturing, may also present a major economic benefit for Alberta and Canada. Figures 1 and 2 below illustrate the existing CF pathways (routes 1, 2, and 3) and a proposed bitumen-derived pathway (route 4) which may require a modification step if high performance CF from asphaltenes is the desired end product.

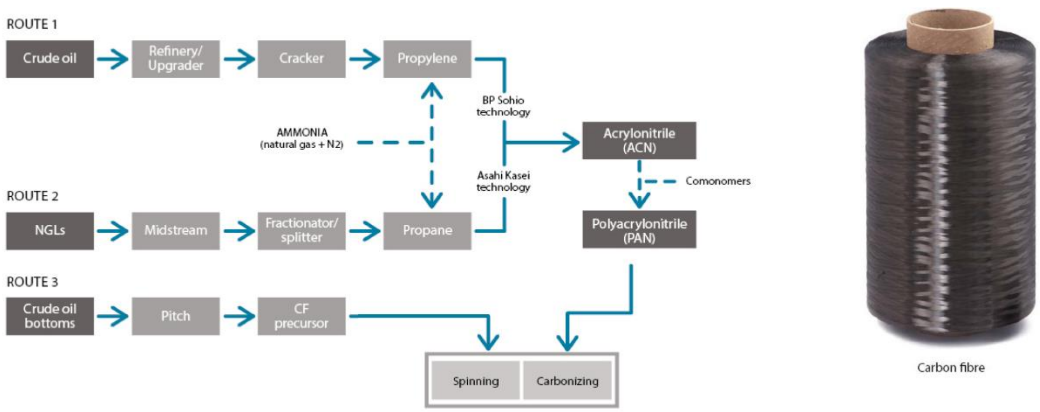

Figure 1 – Carbon Fiber Production Steps *(Source: BBC Phase 2 report, Stantec, 2018)*

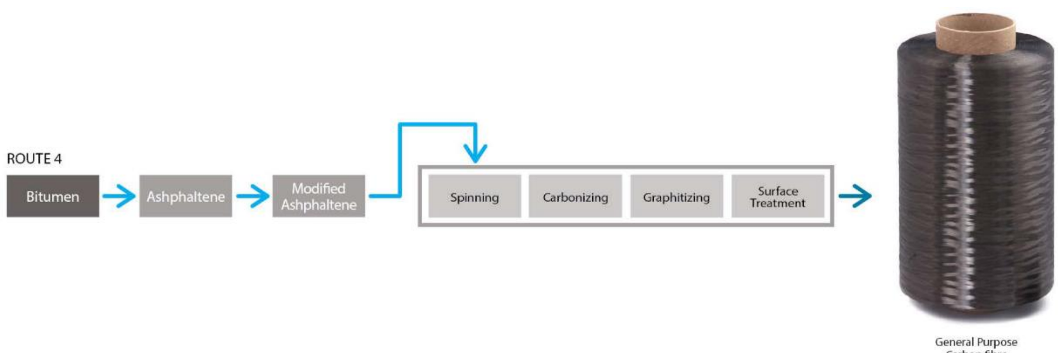

Figure 2 – Modified Carbon Fiber Production Steps *(Source: BBC Phase 2 report, Stantec, 2018)*

There are nominally three categories of carbon fiber products that can be considered:

- High Performance Carbon Fiber (high quality)
- Activated Carbon Fiber – powder and fiber
- General Purpose Carbon Fiber (low quality)

Table 1 shares some of the characteristics of the different classes of carbon fiber with Modulus (measure of stiffness), Tensile stress (strength), heat treatment, orientation, and long-distance order (allows for tight grouping of threads in a tow) differentiators between the types of carbon fibers.

Table 1 - Carbon Fiber Product Classification

Carbon Fiber Type	Typical feed	Heat Treatment Temp (^oC)	Modulus (GPa) (stiffness)	Tensile (MPa) (strength)	Crystalline Orientation	Long-distance order
High Performance-Type I High modulus	Anisotropic (mesophase) Pitch	>2000	500-800	2800-3400	Mainly parallel to the fiber axis	High
High Performance-Type II High Strength	PAN	~1,500	200-400	3500-5800	Mainly parallel to the fiber axis	Low
General Purpose-Type III isotropic	Isotropic Pitch	<1,000	<200	<500	Random	Very Low

Source: Park, S., Carbon Fibers, and BBC Phase 2 Stantec Report

Figure 3 below shows the broad ranging matrix of CF properties from general purpose to high-performance. The desired properties are a function of the end-use product application.

In addition to the classifications noted in Table 1 is a subset (likely value improvement) of General Purpose carbon fiber described as Activated General Purpose Carbon Fiber. This material has the characteristics of activated carbon but comes in a strand or fiber format. This enables specific molds to be created for activated carbon applications (example for filtration).

Different feedstocks and different pre-cursor preparation methods are required to generate the various categories of carbon fiber. A specific pre-treatment step is needed for Athabasca bitumen resid to be used as a feedstock (pitch) for carbon fiber production. To date, no known method of feedstock preparation has been successful in generating HP carbon fiber from Athabasca bitumen asphaltenes and this is the primary unknown portion of the project. It should be noted that heavy gas oil and vacuum residue is used to produce high performance CF however this cut of the barrel competes with its use for valuable transportation fuels.

The proposed potential pathway in Figure 4 replicates the production components and the final product pathways for CF and indicates the potential Suncor feedstocks (mined bitumen (NFT), In-situ bitumen, and/or partially processed bitumen (intermediate streams)) to be considered.

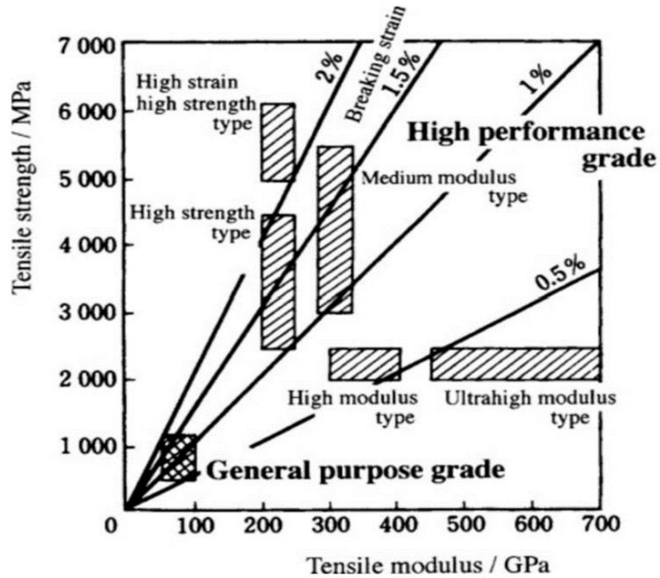

Figure 3 - CF Tensile Modulus vs Strength *(Source: Carbon Fibers, Michio Inagaki, in New Carbons - Control of Structure and Functions, 2000)*

Potential applications for produced carbon fiber are noted in Figure 4 that may demonstrate value generation value from the bitumen resource to the potential final consumer product.

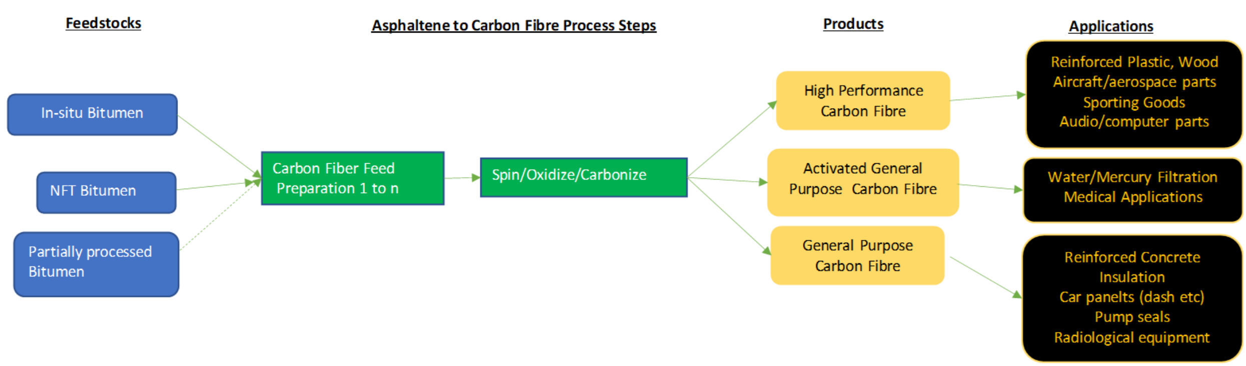

Figure 4 - Potential Deployment Pathway – Bitumen to Carbon Fiber

Knowledge/Technology Gaps:

The cost structure for all types of CF production can be split out into three components:

- Cost of pre-cursor feedstock (PAN, Pitch / Asphaltene);
- CF production (pre-treatment if needed, spinning, carbonization, graphitization);
- End-product manufacturing (composite construction materials and polymers, car parts, aerospace components, turbine blades, etc.).

Each component cost contributes to the overall CF product cost, with the main opportunity to lower the cost being the use of a less expensive feedstock and reduced pre-treatment steps (lower cost and complexity) prior to spinning. Asphaltenes as CF precursors represent a means to realize this opportunity, with the key technical gaps identified as follows:

- Work on chemical, catalytic and thermal conversion processes or combinations of them.
- Improve properties via composite analysis.
- Generate CF samples for testing by manufacturers of CF products.
- Investigate potential partner for the next stage.

The concentration of sulfur and metals is known to be higher in the heaviest fractions of the bitumen barrel, which corresponds to the asphaltenes. Asphaltenes have not been considered as commercial feedstock for carbon fiber production due to the high concentration of complex sulfur compounds and metals impacting carbon fiber quality. If not treated at the appropriate step, these contaminants can prevent spinning of the fiber, and/or the proper alignment and spacing of the molecules within the fiber, preventing high performance carbon fiber creation.

Material in the boiling range 480-593°C (900-1100°F), spanning the heavy gas oil and lighter resid fractions, have been initially targeted for feedstock treatment for high performance carbon fiber. The level of sulfur and metals is such that treatment of this range of hydrocarbon will result in medium to high performance quality carbon fiber. However, this range of material represents a large value driver for refiners to produce motor transportation fuels and is therefore not available for CF production.

In contrast, asphaltenes are pre-cursors to the petroleum coke that is a byproduct of the thermal cracking of bitumen. Coke is a low-value material with high GHG emissions if used as solid fuel (combustion for electricity). Hence if the asphaltenes can instead be subjected to pre-treatment to make a carbon fiber feedstock, a waste stream with high GHG footprint will instead be valorized into a product through which carbon is sequestered in building materials and consumer products.

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.

RESPOND BELOW

Suncor is involved in the entire value chain for bitumen, extracting and processing bitumen to finished products and providing intermediate products to customers for further processing. Asphaltenes concentrations at various stages of processing could be separated and used as feedstock for carbon fiber production. There are numerous potential pathways for asphaltene treatment for high performance carbon fiber that could be developed to create a range of carbon fiber products, but none have been developed yet for commercial use in commercial high performance carbon fiber manufacture. Suncor has already investigated a few promising pathways to convert asphaltenes to mesophase to generate high performance carbon fiber which will likely require a new, innovative solution. The focus going forward, will be on a combination of chemical, heat and catalytic processing to generate mesophase for high performance carbon fiber. Technical gaps identified and being addressed during the project include:

1. Chemistry of asphaltene pre-treatment to generate high performance carbon fiber; while addressing contaminants challenge (lab scale) = PRIMARY GAP to ADDRESS 2. Process to convert asphaltenes to high performance carbon fiber (lab scale validation of asphaltene treatment to generate carbon fiber thread samples for product property analysis) 3. Optimum range (or distillation cut point) of bitumen molecule for conversion/treatment for high performance carbon fiber (lab scale)

The project specific metric is to find a pathway that allows asphaltenes conversion through pretreatment to get a suitable precursor for CF.

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

This project was in collaboration with multiple external parties, in Canada and US, with expertise in different parts of carbon fiber (CF) value chain. As a continuation of the work started in the first phase of this project towards production of high-performance carbon fiber, the project was organized into three key areas to form the methodology to approach the research:

1) Feedstock generation: Asphaltene generation/segregation – solvent extraction (ex. Deasphalting) from Alberta bitumen.

2) Asphaltene treatment – asphaltenes would be subjected to a variety of proprietary thermal, chemical, and/or catalytic treatment and characterized (examples = hot-stage microscopy). Intent with asphaltene treatment is to generate a significant concentration of mesophase material to improve the properties of carbon fiber towards high performance quality. Mesophase is a state of matter intermediate between liquid and solid.

3) Carbon fiber spinning and carbonization– asphaltenes would be melt spun and then thermally treated to make carbon fibers, which then analyzed for mechanical (ex. Strength, Modulus) and molecular (examples, Scanning Electron Microscope (SEM), FTIR). Due to time constraints this step was not completed and only softening point measurements and precursor flow behaviour was assessed.

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

In the first phase of the CFGC project, production of general-purpose CF from asphaltenes was achieved and the produced fibers were characterized. The main target in this phase (phase 2) was to overcome challenges identified in the first phase to produce high quality CF. Several difficulties needed to be addressed in this phase including, how to remove impurities such as sulfur and metals from asphaltenes and how to turn asphaltenes to mesophase.

The feedstock for this project is asphaltenes, both native asphaltenes and asphaltenes from partial upgrading (PUB), from Alberta bitumen. The asphaltenes were successfully produced, from a pilot plant available at the third-party lab, and used in this project.

To convert asphaltenes to suitable precursor for carbon fiber, different pathways (thermal/chemical and catalytic) were tried. Mesophase generation was examined with microscope imaging which then informed a suitable pathway or combination of pathways to make carbon fiber from asphaltenes. Findings related to each pathway is presented below:

Direct conversion to mesophase

Subjecting native and PUB asphaltenes to the same treatment effective on other carbonaceous feedstocks inevitably produced high softening point or low mesophase containing products. Literature suggests that this may be from one or more of the following:

a) Heteroatom content, particularly sulfur;

b) Structure incompatible with forming disk-like mesogens, e.g. an archipelago structure of molecular centers tethered by single bonds or aliphatic moieties;

c) Lack of associated small molecules, aliphatic and aromatic, which give the larger molecules a fluid medium in which to rearrange.

The research team attempted to modify the asphaltenes to address these issues, with the intention of forming a mesophase, and from there a mesophase pitch suitable for spinning. They looked very carefully for anisotropy in hot stage microscopy. The initial material is almost featureless with a very slight degree of anisotropy. This suggests that there are materials in the mix that make up asphaltenes that will order, but unmodified, there is very little effect.

Physical separation/digestion

Different solvents were used to either digest or separate fractions of asphaltenes in order to achieve an intermediate product with mesophase content. Both native and PUB asphaltenes were used with loading ratios up to 40% asphaltenes in the mixture. A conventional mesophase generation process was used with slight modification of operating temperature to initiate and continue mesophase generation. After the mesophase generation and several hours of heat treatment, a microscope image of the product sample was taken to assess the extent of mesophase generation. Figure 5 indicates an example of a microscope image in which mesophase generation can be seen. Results indicated that a mesophase could be generated when a solvent is used for digestion or separation of asphaltenes. The softening point test indicated a suitable softening temperature range (around 300°C) for spinning.

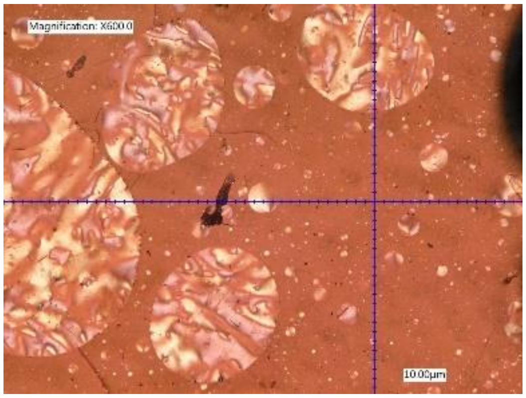

Figure 5: The microscope images show mesophase generation, asphaltenes and solvent mixture. Circles with contour type features in them are mesophase.

In another attempt with solvent digestion, the quinoline insoluble (QI) content of the asphaltenes and solvent was measured before the test and compared with the mixture QI content after mesophase generation. Results indicated a clear increase of QI content of the mixture which is an indirect indication of mesophase generation. However, hot-stage microscope images showed a relatively poor mesophase structure compared to what is expected from a conventional precursor.

Figure 6: Left, Hot stage microscopy image of asphaltene solvent mixture, Right: Hot stage microscopy image of solvent.

Thermal treatment

It is hypothesized that the archipelago structures in asphaltene hinder the formation of stacked mesophasic order (a hypothetical structure is below).

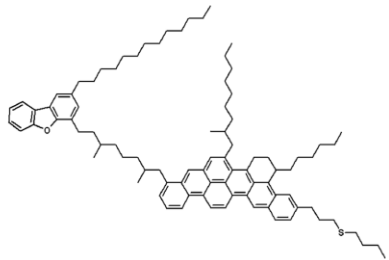

Figure 7: Example of an asphaltene archipelago structure [Edo BoekEdo BoekThomas F HeadenThomas F HeadenJohan T PaddingJohan T Padding, Multi-scale simulation of asphaltene aggregation and deposition in capillary flow January 2010Faraday Discussions 144:271-84; discussion 323-45, 467-81]

It is known that heteroatoms can be removed by hydrogenation, but the aliphatic linkages generally persist. Studies of this sort of compound and cracking them have generally focused on thermal cracking. A series of experiments were conducted under thermal cracking condition. Higher temperature indicated coke formation which is not desirable. Doing softening point tests, the product did not show desired spinnability required for carbon fiber making.

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

Several important learnings were gained during this project:

- Converting asphaltenes to carbon fiber through conventional (known) processes that has been already established for CF making from conventional sources seems to be challenging.
- The main reason could be related to the complex chemical structure of the asphaltenes and/or the level of impurities, removal of which is required to make suitable carbon fiber.
- Asphaltenes pretreatment with solvents (either digestion or partial separation) showed some degrees of mesophase generation. Further optimization might improve the results.
- A combination of chemical and thermal methods might be needed to convert asphaltenes to a precursor that is convertible to mesophase.
- Precursor derived from asphaltenes might have different flow properties (softening point) compared to conventional CF precursor. Developing parameters for asphaltenes precursor spinning is necessary.

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.

RESPOND BELOW

The main technical gaps identified in the first phase of the project was how to convert asphaltenes to high performance carbon fiber. To close this gap, several pathways were suggested including chemical, thermal, catalytic and combinations of these pathways to be tested in the Phase 2.

Outcome 1 = multiple efforts were undertaken to apply conventional mesophase generation process for asphaltenes and found that it is very challenging to get a suitable mesophase without any pre-treatment. Asphaltenes behaviour during mesophase generation was very different compared to conventional feedstock which resulted unsuitable mesophase for further processing.

Outcome 2 = different conversion pathways were tried. Applying only thermal treatment, with some parametric changes on temperature and soaking time, did not result suitable mesophase generation. High temperature treatment resulted in coke formation. Using solvent separation/digestion showed some success in obtaining a mesophase and further optimization might be required to get a suitable mesophase generation.

Outcome 3 = conversion of asphaltenes was proved to be challenging and majority of the project resources were spent on finding a promising conversion pathway. However, examining the flow properties of the produced mesophase indicated that the fiber generation and processing (spinning, stabilization and characterization) might also require additional studies to find a set of suitable parameters for asphaltenes derived mesophase spinnability.

Table 2 shares the clean resources metric outcomes from the project. The continuation of the work from previous CFGC project work, further helped to advance the technology towards higher TRL (3). The findings will be used to update and strengthen the previous patent application. Research work done during this project involved training of highly qualified personnel (HQP). Findings from this project will be very valuable to inform a future pilot design for mesophase generation from bitumen derived feedstock, should Suncor decide to continue the technology development to the next step.

Table 2 – Project Metrics and Targets results

Metric	Project Target	Commercialization / Mobilization Target
Investment in 4 Core Strategic Technology Areas	$824,000	$100's of Millions
TRL advancement	1 to 3	full commercial
Future Capital Investment	N/A	$3-5B
Field pilots/demonstrations	1	
Publications	1-2	3-4
Students Trained (M.Sc., Ph.D., Postdoc)	1-2 Eng undergrads	5-10 post grads
Patents & Records of Invention filed	1-2	2-3
GHG emissions: Projected reductions from future deployment (to 2030)	Data to update models for future projections	TBD

Table 3 is the project metrics and targets. Majority of the project time was spent to overcome the challenge of converting asphaltenes to mesophase. At least one promising process was identified to produce mesophase from asphaltenes. While this was a significant hurdle to overcome and additional work is still required to optimize it, research team was under the time constraints to complete the fiber production and further processing.

Table 3 – Project Metrics and Targets results

Project Success Metrics

Metric	Project Target	Commercialization / Mobilization Target
Develop process to condition asphaltenes to create feedstock for high performance carbon fiber production	Uncover 1-2 processes that can be used to convert asphaltenes or resins from bitumen to high performance carbon fiber. Run CF thread continuously for 5min and obtain <15um diameter thread. Thread Modulus >500 Gpa and Tensile strength >2800MPa.	Commercialize if meets economic hurdles.
Generate CF samples for testing by manufacturers of CF products	Generate 3-4 0.5 kg samples of GP and HP CF	N/A
Investigate potential partners for next stage	Identify 2-3 manufacturers of CF products interested in supporting next stage of development - pilot	N/A

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.

RESPOND BELOW

Economic – An economic analysis was not part of the project scope. Overall, carbon fiber from asphaltenes can provide the following economic benefits:

i) Increase Value and Market Access – Carbon fiber from asphaltenes can provide a new higher value revenue stream for Alberta oil sands producers and a new building block material from bitumen molecules that have the potential to catalyze new Canadian markets for carbon fiber (ex. auto parts, recreational products, reinforced building materials).

ii) Advanced Manufacturing and Materials - Carbon fiber is an advanced material for consumer, industrial and military products, which is not currently a commercial value chain in Canada. It is expected that portions of bitumen can be an inexpensive and reliable feed source for carbon fiber production. Along this new value chain, new Canadian businesses could be created, or existing ones expand

Environmental – If carbon fiber from asphaltenes replaces other heavier materials of construction, the GHG lifecycle analysis of those products could be favourable considering the longevity of carbon fiber and the potential to recycle the material thereby participating in a circular economy. Some benefits/trade-offs that will be considered through producing carbon fiber products from asphaltenes include:

- Diverting asphaltenes to CF instead of combusted petroleum coke.

- The Clean Fuel Standard does not currently provide guidance on solids sequestration, it only indicates that if petcoke is used as fuel for cement or aluminum production it would be subject to the requirements of the CFS.

- Longer life of carbon fiber reinforced construction material, thereby lowering over GHG's on an LCA-basis
- Downstream impacts of achieving low-cost CF (lighter vehicles generating better mileage, lower GHG's)
- Asphaltene produced CF versus high intensity, complex processing of PAN produced CF
- Novel, advanced manufacturing techniques such as 3D printing, lasers, etc. should be considered in future scopes of work.

As developed by Toray, a producer of carbon fiber, (https://www.torayca.com/en/aboutus/abo_003.html), "the environmental impact of carbon fiber was evaluated using the LCA (Life Cycle Assessment) method over its life cycle from digging of material to use and scrapping of carbon fiber product. When the body structure of a car is made 30% lighter using carbon fiber, 50 tons of CO2 will be reduced per 1 ton of carbon fiber over a life cycle of 10 years; when the fuselage structure of aircraft is made 20% lighter using carbon fiber, on the other hand, 1400 tons of CO2 will be reduced under the same condition." Figure 8 illustrates the CO2 reduction over the lifecycle analysis of car and aircraft fabrication.

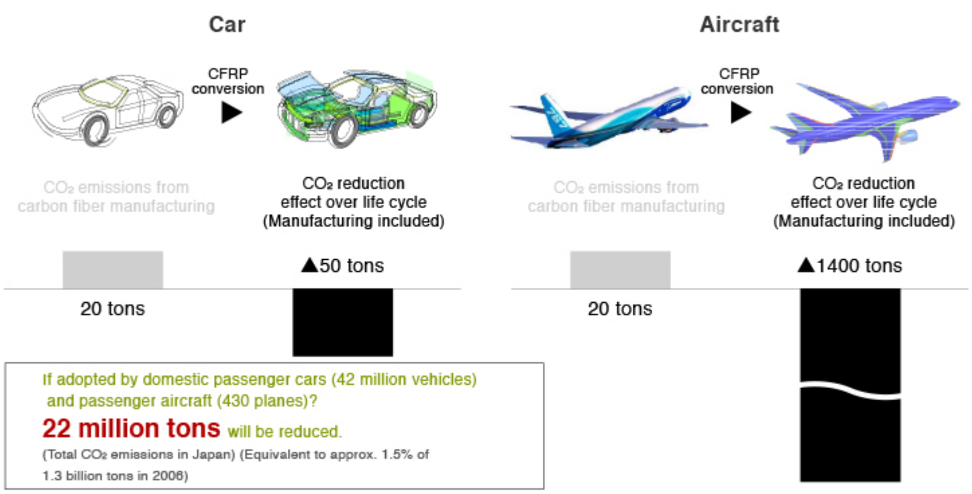

Figure 8 - GHG benefits from use of carbon fiber products. (Source : https ://www.torayca.com/en/aboutus/abo_003.html)

"If passenger cars (42 million vehicles owned, excluding light automobiles) and passenger aircraft (430 planes owned) in Japan adopt carbon fiber to reduce weight and therefore improve fuel economy, 22 million tons of CO2 will be saved. This corresponds to pprox.. 1.5% of total CO2 emissions in Japan in 2006 (1.3 billion tons), which clearly shows why this cutting-edge material is a "trump card" in reducing CO2 and contributing to the global environment." This analysis could be translated to Canada and the development of a carbon fiber industry using asphaltenes as a feedstock.

Social – If realized, this can bring substantial social and health benefits.
The addition of carbon fiber production to Alberta's established oil and gas industry could support diversification efforts. The primary benefits of diversification include an economy that supports multiple businesses reaching out and conducting business with existing secondary beneficiaries such as large offices which require office supply stores, construction companies require lumber yards, restaurants require food service supply, and families require grocery stores, etc. and enabling new businesses such as injection molding consumer product producers. As more and more businesses open their doors, it leads to the growth of supporting industries.

Another benefit of a diversified economy is that it is flexible and not fixed where a community's economic health is not tied to a single industry. This helps protect the economic viability of other industries and prevents the trickle-down effect of massive layoffs in these supporting industries and subsequent declines in property values. A more robust supply chain involving bitumen, Alberta's primary resource, can be established with additional equipment, and labour supply and services. Integration opportunities with specific entities. Then, over time, communities can absorb the impact and continue to develop future resiliency. Another benefit of a diversified economy comes in the form of innovation where optimization efforts in advanced materials to improve carbon fiber production lead to new skills learned locally translating to more and higher paying jobs improving the socio-economic situation for Alberta. With a new industry like Carbon fiber, the innovation ecosystem can continue to grow and develop since the Alberta economy can become stable versus fluctuations to funding in down times thus disrupting longer term innovation projects and initiatives. A healthy innovation ecosystem allows for shared funding models, attracts capital investment and continues to generate new ideas and new products. As one business grows, others can benefit in the development of those new products and services to enhance their operations and boosts their profitability.

Building Innovation Capacity – Multiple PhD's, and engineers were employed in Alberta during this project with these individuals increasing the knowledge base for this subject. Learnings can be built upon in the future to advance the technology.

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

The work in this project further improved our understanding about processing asphaltenes towards making a high-performance carbon fiber. Additional laboratory work is required to further optimize the mesophase conversion process. The next step is the fiber making and testing work. That is understanding spinning parameters for asphaltenes derived mesophase as well as stabilization and carbonization process.

The next immediate stage is to prepare required documents, including business case to justify the next stage of development (pilot stage). The decision to proceed to pilot stage will be subject to Suncor's established project governance processes.

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

While there is no specific publication for this phase of the project, through participations in Carbon Fiber Symposium organized by Alberta Innovates some knowledge sharing was done with the community and stakeholders.

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

Participating in the carbon fiber value chain (precursor or final product) presents an opportunity for economic diversification of the oil sands based on the BBC Phase 2 report from Stantec. Suncor has established a technology development program to evaluate the opportunity assess the opportunity.
Through collaboration with Alberta Innovates, as an important proponent for this idea in Alberta and as an ideal partner for Suncor, techno-economical studies have been done to assess the opportunity towards advancing carbon fiber commercialization. One of the main findings of the first stage of this project was a successful production of general-purpose carbon fiber. Findings of the first stage, were communicated with Alberta Innovates in Suncor’s 2021 report. Building on those previous efforts, the current project focused on lab scale feedstock preparation and generation of carbon fiber with the objective to find a pathway(s) to generate high performance carbon fiber. This will help to get the required inputs to decide whether to advance to the next phase of development.

For this stage of development, third party lab scale facilities were leveraged to analyze, research and test promising routes to commercial grade carbon fiber from asphaltenes. The following results were obtained:

- Different pathways to convert asphaltenes from Athabasca bitumen were tested. These include chemical, thermal and catalytic processes and the combinations of these processes.
- Due to their chemical nature, complexity of molecular structure and presence of impurities converting asphaltenes to high performance carbon fiber was proved to be challenging.
- Despite the challenges noted above, the research team had some success to convert asphaltenes to mesophase, however additional research is needed to optimize the process.