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# PROGRAM GUIDE: Carbon Fibre Grand Challenge – Phase II – 2021 - 2022

## PROGRAM OVERVIEW

### BACKGROUND

The Carbon Fibre Grand Challenge ('CFGC') is a \$15 million three-phase competition with the objective of accelerating the development of large-scale production pathways for short and continuous carbon fibre from bitumen-derived asphaltenes and promoting their use in manufactured products.

The CFGC is part of an initiative by Alberta Innovates to further the development of non-combustion products and their production technologies, derived from bitumen contained in Alberta's oil sands. The latter are amongst the world's largest hydrocarbon resources, with proven reserves of approximately 170 billion barrels and current production of 3 million barrels per day. At present, most bitumen products are destined for energy generation by combustion (such as gasoline, diesel, and heating oil).

The **Bitumen Beyond Combustion ('BBC')** program is intended to:

- diversify the uses of oil sands bitumen, resulting in high-value, large-scale non-combustion products that can be marketed globally, thereby creating a value-add industry built on Alberta's resource;
- reduce greenhouse gas emissions associated with bitumen from production to consumption;
- contribute to global greenhouse gas emissions reduction by creating low-carbon intensity, light weight BBC products to displace high-carbon intensity metal and glass products used in various industrial sectors including transportation and infrastructure.

The BBC program focuses on large-scale non-combustion products and their production technologies that are:

- technically and commercially viable now or can become so;
- competitive with or superior to existing products and production technologies;
- large-scale, requiring at least 100,000 barrels of bitumen per day (bpd) by 2030;
- contributing to Alberta's prosperous, environmentally and socially sustainable diversified economy;

Carbon Fibre ('CF') is one of the identified products that could be made from bitumen. The high strength and stiffness of CF, coupled with low density and high corrosion resistance, make composite

materials that incorporate CF functionally superior to many conventional metals, wood products, and commercial polymers for use in electric vehicles, transportation, infrastructure, construction, and consumer products sectors. Alberta Innovates is working with CF manufacturers and end users, who have been providing market information and target performance specifications. Current demand for carbon fibre is constrained by the high costs of feedstocks and production technologies (primarily based on polyacrylonitrile or pitch) and incorporating fibre into mass produced end-products, like automobile components. The price of asphaltene feedstock from Alberta bitumen is estimated to be one to two orders of magnitude lower than polyacrylonitrile (\$2 – 5 USD / lb) feedstocks.

Carbon fibre from bitumen-derived asphaltenes are estimated to have significantly smaller environmental impacts than CF produced from other sources, including agriculture and forestry. Oil sands operators, CF producers and end users have expressed significant interest in carbon fibre derived from bitumen provided performance and cost criteria can also be met.

The Carbon Fibre Grand Challenge is directed towards funding the development of technologies that can convert Alberta oil sands asphaltenes ('AOA') into CF.<sup>1</sup> Alberta Innovates is working with partners to support Phases II and III of the CFGC. The Clean Resource Innovation Network ('CRIN') is co-funding Phase II of the CFGC with Alberta Innovates.

## PROGRAM DETAILS

There are three phases to the CFGC. Phase I will conclude in February 2021. This program guide provides specific details for Phase II, and general details for Phase III. A specific program guide will be created for Phase III prior to the Phase III registration period.

### Phase II – Scaling: July 2021 - December 2022

- **Goal:** consolidate learnings from Phase I to produce carbon fibre from AOA at lab scale with properties desired by commercial end-users; and to develop a process with line of sight to a demonstration plant that can be commercially scaled.
- **Applicant Objective:** produce CF that meets minimum quality specifications desired by commercial end users, using bitumen-derived AOA and develop a pathway to managing the sulfur and metal content from the asphaltenes.
- **Targeted Outcomes:**
  - carbon fibre production of >10 grams per day with tensile strength >3,000 MPa and modulus >250 GPa or other strength/modulus combination that meets a demonstrated commercial need;
  - potential end uses identified and/or validated;
  - if short fibres are the project focus in Phase II the target length is 6 mm with 7 µm diameter or other length/diameter combination that meets a demonstrated commercial need;

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<sup>1</sup> Asphaltenes are defined as the fraction of the bitumen that is soluble in toluene and insoluble in n-alkane solvents. Because they are defined by solubility, there is no single molecule, chemical composition or structure that defines an "asphaltene". More information on AOA can be found in Appendix B.

- preliminary energy requirements for the proposed CF manufacturing process and corresponding greenhouse gas emissions profile;
  - preliminary cost expectations for carbon fibres manufactured using the process developed in Phase II.
- **Funding:** \$200,001 up to \$500,000 CAD awarded to successful applicants. A total \$5,000,000 CAD is available. Following a modest initial payment, funding will be provided on a reimbursement basis as milestones are achieved as the project progresses. Milestones are aligned with the project implementation plan.
  - **Matching Funds:**
    - 50% of the total eligible costs is the target for the project, however, consideration will be given to applications with less than 50% matching funds
    - Overhead will be considered as an in-kind contribution for up to a maximum of 30% of the total budget
  - **Application Deadline:** April 27, 2021 at 2:00 PM MDT

### Phase III – Demonstration: March 2023 – December 2024

- **Program Goal:** achieve pre-commercial demonstration of CF manufacture that enables immediate commercial investment.
- **Applicant Objective:** design, development, and demonstration of a pre-commercial CF production process using AOA.
- **Minimum Outcome:**
  - Continuous production of >10 kg per day;
  - Tensile strength >3,500 MPa and modulus >250 GPa or other strength/modulus combination that meets commercial needs;
  - Projected commercial cost of CF <US\$9 per kg;
  - Line-of-sight to scale CF production process to 2000 tonnes or greater per year;
  - Demonstrated market potential of products incorporating CF, utilizing >2,500 tonnes per day of AOA by 2030;
  - Potential of mass manufacture of identified products incorporating the CF, concepts for their re-use and end-of-life disposition;
  - Estimate of lifecycle greenhouse gas emissions and other socio/environmental impacts of the CF and their products.
- **Funding:** \$3,000,000 CAD Grand Prizes awarded to 3 Winners (total \$9,000,000 CAD) as lump-sum at end of Phase III.
- **Tentative Registration Deadline:** February 28, 2023

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*In this call for proposals, Alberta Innovates & CRIN are making available up to \$5,000,000 CAD over an 18-month period to support Projects that align with Phase II of the CFGC. Funding for individual Projects can range from \$200,001 to a maximum of \$500,000 CAD. This will effectively position successful Phase II applicants for Phase III.*

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**Participation in any Phase of the CFGC is not dependent on having applied to or been awarded funding in any previous Phase.**

For applicants, CFGC funding offers an opportunity to reduce innovation risk, offset internal funding competition within their organizations and enables collaboration beyond individual organizations. The proposed Projects should have a line of sight to ultimately enabling benefits to Alberta and Canadian based companies and/or institutions through the development of CF from Alberta bitumen.

## HOW THE PROGRAM WORKS

### Eligibility

#### (a) Applicant Eligibility Criteria

The Carbon Fibre Grand Challenge Phase II competition is open to technology developers, industry (including small, medium and large size enterprises), industry associations, research and development (R&D) organizations, post-secondary institutions, not-for-profit organizations, and government research labs, providing they are legally able to execute the Alberta Innovates (for International or Canadian research teams) and the CRIN (for Canadian research teams only) [Investment Agreements](#) found on the Alberta Innovates CFGC website . Applicants are not required to be based in Alberta or Canada but must demonstrate a clear value proposition for Alberta and Canada. Eligible applicants must have demonstrated expertise with respect to:

- applying scientific and engineering fundamentals relevant to the manufacture of CF and their associated production technologies;
- undertaking and successfully completing scientific and technical laboratory and other small-scale practical work on or relevant to CF production;
- utilizing results and conclusions from laboratory and other small-scale work to establish the viability and competitiveness of production technologies, such ability to include experience with preparing process flowsheets (with mass and energy information and basic equipment specifications) for purposes of process evaluation and scale-up;
- identifying and addressing critical business issues, including CAPEX and OPEX estimates, market characteristics, and environmental and social acceptance;
- addressing scientific, technical, business, and environmental challenges and opportunities.

All Applicants must be in good financial standing with CRIN and Alberta Innovates, including the latter's subsidiaries InnoTech Alberta and C-FER Technologies.

Collaboration with other Project Partners is highly encouraged and Projects that demonstrate end-user engagement and formal partnerships will receive additional favourable consideration. This can be demonstrated through end-user funding, in-kind contributions, letters of support, project advisory, etc.

### For International Applicants

Carbon Fibre is a controlled material governed by the Applicant country's national export control laws. Should the Applicant be awarded funding in the Carbon Fibre Grand Challenge – Phase II, as part of Alberta Innovates' reporting requirements, the Applicant will be required to report, in a confidential manner, technical details regarding the testing methods and manufacturing processes related to the carbon fibre developed in the Applicant's project. The Applicant may also be asked to provide a sample of the carbon fibre manufactured in the project to Alberta Innovates. Applicants should ensure that they are familiar with their national export control regulations related to carbon fibre materials and are able to comply with Alberta Innovates' reporting obligations in the event that success in the Phase II project triggers export control regulations and associated licensing requirements within their jurisdiction. Export control regulations and/or failure to obtain an export clearance (to the extent required) do not absolve the Applicant from the responsibility of reporting on technical details in a confidential manner and providing a sample to Alberta Innovates (and the Alberta Government who is Alberta Innovates' sole shareholder). If an Applicant is unable to ensure that the reporting obligations can be fulfilled under their national export control regulations, then an application should not be submitted to CFGC – Phase II.

### **(b) Project Partner Eligibility Criteria**

Any Project Partner(s) is(are) required to satisfy the following criteria:

- demonstrate the relationship between the Applicant and the Project Partner(s) does not create a conflict of interest;
- be in good financial standing with Alberta Innovates and its subsidiaries InnoTech Alberta and C-Fer Technologies;

Other funding agencies are considered eligible Project Partners.

### **(c) Project Eligibility Criteria**

To qualify for funding, all Projects must:

- be completed by December 31, 2022; and
- submit to other criteria that Alberta Innovates and/or CRIN may develop from time to time.

### **(d) Feedstock samples**

Asphaltenes used in Projects funded by this Grand Challenge must be derived from Alberta oilsands bitumen. **No exceptions will be made.** Applicants may elect to source AOA on their own or through the Asphaltene Sample Bank (ASB) operated by InnoTech Alberta. Applicants are asked to indicate on the application form if they will source samples from the ASB. Applicants that do not source AOA from the Asphaltene Bank are required to demonstrate the Alberta origin of the asphaltenes and submit a sample to Alberta Innovates for characterization.

For applicants that elect to source samples from the ASB, sample specification/property sheets for the four available samples (S1, S2, L1 and L3) can be found on the [Carbon Fibre Grand Challenge website](#) under the Program Resources heading. All samples in the ASB offered as part of Phase II of the Carbon Fibre Grand Challenge have the potential to form carbon fibre, although the processing prior to carbon fibre manufacture may differ from sample to sample. All the samples in the sample bank will likely require some form of processing prior to being suitable for carbon fibre manufacture. Please review the sample specification sheets and consider the information provided when selecting the samples and designing the work plan scope and outcomes.

Sample are offered at a cost of \$80 CAD per kg plus shipping and taxes. Please include a line item for asphaltene cost in the proposed budget.

## PROGRAM OBJECTIVES AND PERFORMANCE MEASUREMENT

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*Over the life of a Project, Alberta Innovates and CRIN employ an active project management philosophy, regularly monitoring performance and supporting the Applicant to reach their objectives.*

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Once Projects are completed, Alberta Innovates and CRIN continue to monitor performance to accurately evaluate the economic, social and environmental benefits realized for Alberta and Canada.

All Investment Agreements outline performance indicators tracked over the course of the Project and the responsibilities of the Applicant to report on outcomes subsequent to the completion of the Project. Alberta Innovates has a common set of performance metrics it monitors, both at the individual Project level and for the aggregate Program. These are highlighted on the next page.

# OBJECTIVES AND PERFORMANCE METRICS



## PROGRAM PERFORMANCE INDICATORS

Increase employment, resource revenues, economic diversification, and improved export potential.

Attract investment capital

Increase industry sales revenue

Increase in the value of a barrel of Alberta bitumen

Unique products/processes developed

Number of commercial BBC products

End user participation in projects

SHORT TERM



## PROGRAM SHORT TERM OUTCOMES

New products/processes

GHG emissions reduction

Value-added use of bitumen feedstock

Economic diversification

LONG TERM



## ALBERTA OBJECTIVES

Economic Diversification

Reduce GHG Emissions

Improve Oil Sands Efficiency

Grow Alberta's Green Economy



## APPLICANT OBJECTIVES

Technology development & scale-up

Reduce innovation risk

Offset internal funding competition

Enable collaboration beyond individual organizations

Attracting partner funding for technology development and demonstration

## BENEFITS TO ALBERTA AND CANADA

Funding provided to the Carbon Fibre Grand Challenge in Phase II requires that benefits obtained from the development of carbon fibres are experienced in Alberta and Canada. Applicants will be required in the CFGC Phase II funding application to describe how the knowledge, IP and outcomes of the research will be commercialized in Alberta and Canada. This is a very important component of the application.

## HOW FUNDING WORKS

### (a) Project Funding

Funding for successful Applicants in Phase II will be between \$200,001 - \$500,000 CAD.

The Program is targeting matching support of up to 50% of the total Project costs. The remaining 50% of funding can be a combination of cash and in-kind support from the Applicant and/or other Project partners. Preference will be given to applications with a greater matching cash funding. Consideration will still be given to applications with less than 50% matching funds although it will impact the competitive standing of the proposal.

Funding will be dispersed to successful Applicants on a milestone completion basis. **All Phase II Projects must be completed by December 31, 2022.** Applicants should plan for an approximate 18-month project time-frame. A project can begin once an Investment Agreement is signed between an applicant and either or both of Alberta Innovates or CRIN. CRIN will fund only Canadian applicants, while Alberta Innovates can fund either Canadian or International applicants.

Funding support from this program is available to international applicants, but preference will be given for collaboration with Canadian partners including Canadian IP ownership.

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*Alberta Innovates and CRIN encourage co-funding of Projects with other funding agencies and does not limit the amount of stacking towards the applicant's contribution. However, reliance on uncommitted funding could delay or hinder contracting with Alberta Innovates or CRIN.*

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### (b) Eligible and ineligible expenses

All funding for the CFGC program will be disbursed through Alberta Innovates and/or CRIN and successful applicants will be required to sign an Investment Agreement with either Alberta Innovates and/or CRIN. Alberta Innovates and CRIN only fund reasonable costs incurred subsequent to a signed Investment Agreement between Alberta Innovates or CRIN and an Applicant. Any costs incurred prior to the signing of the Investment Agreement, or costs greater than market prices are deemed ineligible. Please refer to the [Investment Agreements](#) found on the Alberta Innovates CFGC website for further information and an in-depth description of eligible and ineligible costs. The chart on the next page provides a summary of eligible and ineligible expenses.

## SUMMARY OF ELIGIBLE AND INELIGIBLE EXPENSES

Category	Eligible Expenses	Ineligible Expenses
<b>Labour</b>	<ul style="list-style-type: none"> <li>✓ Labour costs for those individuals specifically identified as working on the Project; Professor's time as in-kind</li> <li>✓ Overhead up to 30% of total budget is eligible as an in-kind contribution.</li> </ul>	<ul style="list-style-type: none"> <li>✗ Overhead costs as cash contribution</li> <li>✗ Professional training &amp; development</li> <li>✗ Professional fees unless directly related to the Project</li> </ul>
<b>Materials</b>	<ul style="list-style-type: none"> <li>✓ Reasonable material costs which can be specifically identified for use in the Project</li> </ul>	
<b>Capital Assets &amp; Software</b>	<ul style="list-style-type: none"> <li>✓ Capital improvements</li> <li>✓ Capital equipment</li> <li>✓ Software or information databases</li> </ul> <p><i>Note: Eligible costs will be pro-rated to the Project time frame based on the asset's expected economic life</i></p>	<ul style="list-style-type: none"> <li>✗ Acquisitions of land or buildings</li> <li>✗ The undepreciated value of eligible capital costs which extends beyond the Project term</li> </ul>
<b>Travel</b>	<ul style="list-style-type: none"> <li>✓ Travel, including mileage, low economy airfare, and accommodation for the purposes of executing the Project</li> </ul>	<ul style="list-style-type: none"> <li>✗ Passport or immigration fees</li> <li>✗ Costs relating to meals, entertainment, hospitality and gifts</li> <li>✗ Reimbursement for airfare purchased with personal frequent flyer programs</li> <li>✗ Commuting costs between place of residence and place of employment</li> </ul>
<b>Sub-contractors</b>	<ul style="list-style-type: none"> <li>✓ Services or products of another entity</li> </ul>	<ul style="list-style-type: none"> <li>✗ Costs associated with applying for government grants and Programs</li> <li>✗ Provisions for contingencies, technical or professional journals</li> <li>✗ Routine testing and maintenance</li> </ul>
<b>Other</b>	<ul style="list-style-type: none"> <li>✓ Costs which Alberta Innovates pre-approves in writing as an eligible expense</li> </ul>	<ul style="list-style-type: none"> <li>✗ Collection charges, allowance for interest on debt, fines and penalties</li> <li>✗ Federal and provincial income taxes, goods and services taxes</li> <li>✗ Expenses for Projects or activities outside the approved Project</li> </ul>

## HOW TO APPLY



### STEP 1 Application

This is a one stage application process. Applications will be submitted electronically using the Alberta Innovates online intake system; the link to the application system can be found below.



### STEP 2 Evaluation

The evaluation process is highly competitive and only the highest-quality projects will be considered.

Details regarding the Alberta Innovates' and CRIN merit review can be found in Appendix C of this guide.



### STEP 3 Project Management

Successful Applicants will execute an Investment Agreement with Alberta Innovates and/or CRIN to proceed with the activities of the Project.

Alberta Innovates will provide on-going management, receiving and evaluating Applicants' reporting of milestones and payments on each milestone based on achievement of the objectives

Alberta Innovates continues to require information from the Applicant for five years following the completion of the Project in order to measure long-term benefits.

## APPLICATION LINK:

Applications will be submitted through [Alberta Innovates' SmartSimple portal](#) using the intake form "Carbon Fibre Grand Challenge".

## COMPETITION TIMELINES

Activity	Date
Competition Open	March 9, 2021
Competition Webinar	March 23, 2021, 10:00 MDT
Application Deadline	April 27, 2021, 14:00 MDT
Notification Letters Provided to Applicants	Late May 2021
Contracting	June 2021
Project Start	July 2021
Latest Date for Project Completion	December 31, 2022

## EVALUATION PROCESS

Alberta Innovates and CRIN will leverage internal staff and external expert reviewers to evaluate Applications submitted. Alberta Innovates and CRIN retain the sole right to determine the evaluation process and do not disclose the names of reviewers to ensure their objectivity and impartiality. All reviewers are subject to confidentiality, non-disclosure, and conflict of interest policies set by Alberta Innovates and CRIN.

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*The assessment criteria and all investment decisions are at the sole discretion of Alberta Innovates and CRIN.*

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## TERMS AND CONDITIONS

This Program Guide is intended as a high-level overview of Phase II of the Carbon Fibre Grand Challenge. It provides interested parties with a roadmap of what to expect over the lifecycle of a Project, from the Application stage, during the Project and post-completion. Should you have any questions about this guide or what is expected, please contact Alberta Innovates. Please be aware Alberta Innovates and CRIN may modify this guide from time to time in keeping with any changes to the Program.

Alberta Innovates will only correspond in writing to the person named in the application form as the one authorized to speak for the Applicant.

Once we have evaluated and approved an Application for funding, Alberta Innovates and/or CRIN will require the Applicant to sign a standard form Investment Agreement. A copy of the Alberta Innovates and CRIN [Investment Agreements](#) are available on the Alberta Innovates CFGC website. The Investment Agreement sets out the roles, responsibilities and obligations of the various Parties to ensure a successful Project. Alberta Innovates will not provide any funding until the Investment Agreement has been signed by all Parties.

Alberta Innovates and CRIN will only fund Applicants who have satisfied all eligibility criteria. Meeting the eligibility criteria does not guarantee access to funding, and all funding decisions will be made by Alberta Innovates and CRIN at their sole discretion.

## DIVERSITY, EQUITY, AND INCLUSION

The Alberta research and innovation (R&I) ecosystem is stronger and more sustainable when it is broadly reflective of the overall diversity of our community. Alberta Innovates and CRIN strive to ensure all interested and qualified parties have an equitable opportunity to participate and contribute. Historically, there have been a number of groups/populations that have been under-represented in the Alberta R&I landscape including:

- Women entrepreneurs/researchers;
- Indigenous entrepreneurs/researchers;
- Remote/small community entrepreneurs/researchers; and
- New immigrant entrepreneurs/researchers.

We are guided by the principles of:

- **Diversity** – both internal and external participants to our processes are comprised of a varied composition of demographics;
- **Equity** – our processes support equal access across all demographics; and
- **Inclusivity** – our processes proactively work to include underrepresented segments of the R&I landscape.

As part of its commitment to Diversity, Equity and Inclusion (DEI), Alberta Innovates will:

- Collect data in the grant application on a voluntary basis to better understand diversity;
- Provide grant application navigation support to applicants from under-represented groups; and
- Integrate a DEI focus into its due diligence processes including striving to have diverse review committees to foster unbiased decision making.

## CONTACT INFORMATION

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## APPENDIX A

### Key Carbon Fibre from Asphaltene Knowledge & Technology Gaps

Alberta Innovates has identified five key knowledge gaps that pertain to manufacturing carbon fibre from Alberta oil sands asphaltenes.

1. **Mesophase Requirement:** Formation of a mesophase is important in the production of CF from pitch. It is unknown whether a mesophase is required for making CF (with the desired specifications) from Alberta oil sands asphaltenes.
2. **Impact of Sulphur and Metals:** Alberta oil sands asphaltenes have substantial concentrations of sulfur and metals. Their fate in the asphaltene to CF manufacturing process and their impact on the properties of the product carbon fibre needs to be better understood.
3. **Carbon Fibre Production Fundamentals:** While the chemistry and physics (e.g. rheology, heat, and mass transfer) of steps in the production of CF from polyacrylonitrile (PAN) and pitch are well understood, similar knowledge is currently missing for feedstocks derived from Alberta oil sands asphaltenes. For example, a process to develop short fibres that does not involve chopping continuous fibres is currently unknown for carbon fibre manufactured from Alberta oil sands asphaltenes.
4. **Large-Scale Carbon Fibre Production:** Alberta currently produces approximately 3 million barrels per day of oil sands bitumen, containing 15 to 20 wt% asphaltenes. The target for carbon fibre production from Alberta oil sands bitumen is at least 100,000 bbl/day which corresponds to production of over 400,000 tonnes of carbon fibre per year. Modern production trains, which utilize PAN and pitch feedstocks, have production capacities in the range of 1,500-2,000 tonnes of CF per year. Conceptualization and development of CF production trains that have substantially larger capacities and utilize Alberta oil sands asphaltenes are missing.
5. **Economics, Energy Requirements and Greenhouse Gas emissions:** The economics, energy requirements, and GHG emissions of CF production processes based on Alberta oil sands asphaltenes need quantification.

## APPENDIX B

### Asphaltenes FAQ

- 1. What are asphaltenes?** Asphaltenes are defined as the fraction of petroleum, including oil sands bitumen, that is soluble in toluene and insoluble in n-alkane solvents. Because they are defined by solubility, there is no single molecule, chemical composition or structure that defines an “asphaltene”.
- 2. How are asphaltenes isolated?** Asphaltenes can be isolated from bitumen using solvents. Different solvents give rise to different asphaltene yields from bitumen. Industrial separations use propane, butane or pentane. Laboratory methods, as standardized by ASTM, use n-pentane (C5) and n-heptane (C7). Raw Athabasca bitumen contains circa 15% by weight of asphaltenes insoluble in n-heptane, and 20% by weight of asphaltene insoluble in n-pentane. Asphaltenes may also be separated from partially upgraded bitumen.
- 3. What is the chemical composition of Alberta oil sands asphaltenes?** The composition of Alberta oil sands asphaltenes can vary depending on the solvent used to isolate the asphaltenes but they are very similar. Chemical compositions for n-pentane and n-heptane precipitated asphaltenes are listed in the table below. <sup>2</sup>

**Chemical Composition of Alberta Oil Sands Asphaltene by Weight**

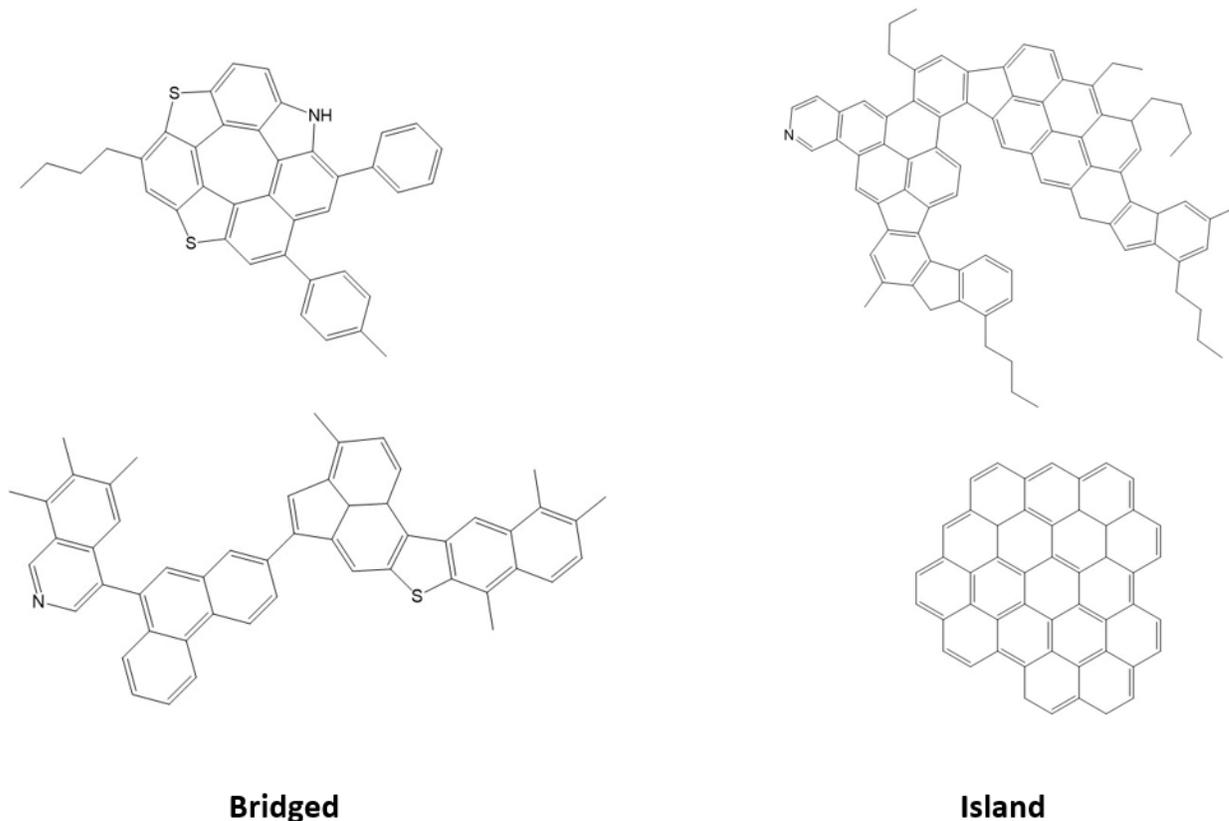
Isolation Solvent	C	H	N	O	S
n-pentane	79-80%	8%	1-2%	3-4%	7-8%
n-heptane	78-79%	7-8%	1-2%	4-5%	8%

The asphaltenes also contain circa 800-1,000 parts per million by weight of vanadium and 400-600 parts per million of nickel, as organometallic compounds. Processing of bitumen by thermal, catalytic or oxidative reactions changes the asphaltene content, and also changes the elemental composition of the asphaltene fraction.

- 4. What is the structure of asphaltenes?** The carbon to hydrogen atomic ratio of asphaltenes is greater than 1 corresponding to a highly unsaturated molecular environment on average. Asphaltenes contain multi-ringed aromatic molecules often with aliphatic chains on the periphery. Heteroatoms can be found both within the aromatic rings (mainly S and N) and as part of the peripheral chains (mainly S and O). Two predominant motifs dominate the structure of asphaltene molecules, as illustrated below in Figure 1.

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<sup>2</sup> Strausz, O.P., and Lown, E.M., (2003). “*The Chemistry of Alberta Oil Sands, Bitumens, and Heavy Oils*”. Page 495. Calgary: Alberta Energy Research Institute. ISBN 0778530965



**Figure 1** – Molecules exemplifying the bridged and island motif found in the structure of asphaltene constituents.

Multiple aromatic cores joined by bridging groups dominate in Athabasca bitumen, while the island motif of large aromatic rings with alkyl groups is less abundant<sup>3</sup>. Schuler et al. have reported structures of single molecules found in asphaltenes that have been characterized by atomic force microscopy.<sup>4</sup> The abundance of different structures depends on the source of the asphaltene and any prior processing of the bitumen. Asphaltene molecules tend to aggregate strongly in bitumen and solution, giving apparent molecular weights that are higher than the true range of 400-1,000 Da.

5. **Are asphaltenes a solid or liquid at ambient temperature?** Asphaltenes are a glassy solid at ambient temperature. Depending on preparation methods, they may either be a powder or large lumps.
  
6. **What is the melting point of asphaltenes?** As complex mixtures, they exhibit no defined melting point. The softening point depends on the composition of the mixture, ranging from circa 100°C for some industrial asphaltene-rich fractions to over 200°C for n-heptane insoluble asphaltenes.

<sup>3</sup> Chacon-Patino et al. "Advances in Asphaltene Petroleomics. Part 3. Dominance of Island or Archipelago Structural Motif Is Sample Dependent", *Energy & Fuels*, 2018, 32, 9106-9120.

<sup>4</sup> Schuler, B., et al., *Energy & Fuels*, 2017, 31, 6856-6861

7. **What is the viscosity of asphaltenes?** The apparent viscosity of asphaltenes is highly dependent on temperature, above the softening point, and composition. A small amount of bitumen components that are soluble in n-pentane will significantly reduce the apparent viscosity at a given temperature. In all cases, the apparent viscosity decreases rapidly as the temperature is increased from the softening point. Asphaltenes can exhibit viscoelastic behavior depending on temperature and composition.
8. **Is ‘asphaltenes’ another term for ‘petroleum pitch’?** No, asphaltenes are fundamentally different from petroleum pitch used in the manufacture of some carbon fibre. Pitch for carbon fibres is most commonly produced by cross-linking mixtures of small aromatic groups, for example, alkyl-naphthalenes. Caution must be taken when reading literature related to carbon fibre derived from petroleum pitch and projecting potential outcomes using asphaltenes.
9. **Are there any references that can provide additional information on asphaltenes?**

Recent references (past 3 years) relevant to understanding asphaltenes are:

Chacon-Patino et al. “Advances in Asphaltene Petroleomics. Part 3. Dominance of Island or Archipelago Structural Motif Is Sample Dependent”, *Energy & Fuels*, 2018, 32, 9106-9120.

Schuler, B., *et al.*, *Energy & Fuels*, 2017, 31, 6856-6861

#### Books

Gray, M.R. (2015) “*Upgrading Oilsands Bitumen and Heavy Oil*”, University of Alberta Press, ISBN 978-1-77212-035-6, 496 pp.

Strausz, O.P., and Lown, E.M., (2003). “*The Chemistry of Alberta Oil Sands, Bitumens, and Heavy Oils*”. Calgary: Alberta Energy Research Institute. ISBN 0778530965, 695 pp.

## APPENDIX C

### Detailed Evaluation Criteria – Phase II

A Phase II application will be reviewed based on eight broad criteria, with full details evident in the CFGC Phase II application form. A summary of those criteria is below:

1. **The Innovation Opportunity:** this section focuses on the carbon fibre manufacturing process developed by the applicant, how the process works, its uniqueness and how it will address the scaling challenges of converting asphaltenes into carbon fibre.
2. **Market Opportunity:** this section focuses on the proposed market opportunity for the carbon fibre to be generated in this proposal. This section is where applicants that have chosen different targeted mechanical properties will need to justify the market demand/opportunity for that type of carbon fibre.
3. **Proposed Commercialization Pathway:** this section focuses on the key steps required to achieve commercialization from the current state. These steps include technical, business, financial, etc..
4. **Project Overview and Work Plan:** this section focuses on the work that will be completed in the project to achieve the desired outcomes.
5. **Budget:** this section includes a description of the budget and financing for the project.
6. **Team:** this section highlights the key team members, both from the applicant and partners and how their experience will lead to success in the project
7. **Project Risk Analysis:** this section describes key risks the project may face and what the applicant team will do to mitigate those risks
8. **Impacts - Alberta & Canada Implementation Plan:** this section will be evaluated on how the applicant will first implement the knowledge, IP and learnings from this Phase II project and a successful Phase III project in Alberta and Canada and what steps will be taken to ensure this will lead to production of Carbon Fibre in Alberta and Canada.

**Signatures:** An authorized representative of the lead applicant's employing organization must sign the application form and may indicate if Alberta Innovates can share the application with trusted funding partners.