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:	**Development of Next Generation Membrane Electrode Assembly Using Alberta Asphaltene-Derived Novel Nanoporous Carbon Materials for High Performance PEM Fuel Cell**
Alberta Innovates Project Number:	212200862
Submission Date:	April 30, 2024
Total Project Cost:	$472,080
Alberta Innovates Funding:	$236,040
AI Project Advisor:	Paolo Bomben

2. APPLICANT INFORMATION:

Applicant (Organization):	**Momentum Materials Solutions Corp.**
Address:	253147 Bearspaw Road, Calgary, AB
Applicant Representative Name:	Chengying (Arlene) Ai
Title:	CEO
Phone Number:	5875004052
Email:	arlene@momentummaterials.com

3. PROJECT PARTNERS

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

RESPOND BELOW

We would like to thank Alberta Innovates, University of Calgary and Giner for their contributions to this project.

A. EXECUTIVE SUMMARY

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

RESPOND BELOW

Objective:

Momentum Materials Solutions, an Alberta start-up, in this project aims to transform low-value asphaltenes, a by-product of Alberta's oil and gas industry, into high-value, advanced carbon materials for hydrogen fuel cell applications.

Key Results:

- *Successful conversion of Alberta asphaltenes into mesophase pitch and nanoporous carbon materials, specifically nanoporous carbon scaffold (NCS) and colloid imprinted carbon (CIC).*
- *Production and testing of these materials in membrane electrode assemblies (MEAs) for proton exchange membrane fuel cells.*
- *Achieved high performance and durability in single fuel cell tests.*

Learnings:

- *Alberta asphaltenes have significant potential for use in manufacturing advanced nanoporous carbon materials.*
- *The developed NCS and CIC materials can effectively enhance the performance of hydrogen fuel cells.*

Outcomes:

- *Demonstrated that Alberta asphaltene-derived materials can be used to create efficient and durable MEAs.*
- *Validated the potential for a new supply chain in fuel cell MEA production.*
- *Trained 4 highly qualified personnel in the preparation of mesophase pitch and nanoporous carbon materials from Alberta asphaltenes.*
- *Trained 2 highly qualified personnel in the fabrication of MEA from Alberta asphaltenes and testing them in hydrogen fuel cells.*

Benefits:

- *Diversification and enhancement of Alberta's economy by creating a new, high-value use for asphaltenes.*
- *Contribution to the development of high-performance hydrogen fuel cells, supporting net-zero emissions initiatives.*

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

Membrane electrode assembly (MEA) is the heart of a polymer electrolyte membrane fuel cell (PEMFC) and the target market for this technology includes PEMFC, hydrogen vehicles, hydrogen drones and so forth. The advanced nanoporous carbons are also promising for hydrogen production (i.e. proton exchange membrane electrolyzer), and batteries (i.e. lithium-sulfur battery and lithium-ion battery). This project will also generate knowledge on transferring Alberta asphaltene into value-added precursor materials that can be the feedstock for many other advanced carbon products.

Knowledge or technology gaps

This project addresses the quality and cost issues with the current membrane electrode assemblies (MEA) of hydrogen fuel cells produced using Alberta asphaltene-derived novel nanoporous carbon materials. Hydrogen fuel cells are the most promising alternative energy devices for long-distance and heavy-duty electric vehicles because of their high-power density, efficiency, and zero carbon emissions. A membrane electrode assembly (MEA) is at the heart of a hydrogen fuel cell, and the global market for MEAs is projected to be $15 billion by 2025. However, the cost of producing an MEA is high and the durability is often poor, partly due to variability in the carbon powder support materials and the irreproducibility of distribution of the ion-conducting polymer throughout the packed carbon particles. The quality of an MEA is also hard to control, leading to varied fuel cell performance. Momentum Materials Solutions is developing a new generation MEA based on a patented nanoporous carbon scaffold (NCS) film, as well as proprietary colloid imprinted carbons (CICs) to solve these problems. Mesophase pitch is one of the core raw materials for the production of NCSs and CICs. However, Momentum Materials is currently heavily dependent on synthetic mesophase pitch suppliers, which increases the production cycle, expense and creates a resource risk. This project will address this resource risk by utilizing Alberta asphaltenes as the raw material for manufacturing NCSs and CICs.

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

Knowledge or Technology description: Asphaltene is an abundant by-product of Alberta's oil and gas industry and a highly aromatic material, which has significant promise in terms of its utilization in manufacturing the NCS and CIC materials. Momentum Materials aims to convert the low-value Alberta asphaltenes into novel and high-value NCS and/or CIC materials for use in high performance hydrogen fuel cells, which could create a new supply chain for fuel cell MEA production and also benefit Alberta's economy. This project will focus on: (1) developing a method to convert Alberta's asphaltenes into high-quality mesophase pitch feedstock suitable for NCS or CIC manufacturing, and (2) developing MEAs using the asphaltene-derived NCS and/or CICs. The expected outcomes of this project should include a templated and scalable procedure to convert Alberta asphaltene into the NCS or CIC materials, and the validation of a high performance and durable MEA derived from asphaltene-prepared NCS or CIC.

Updates to Project Objectives: There have been no significant changes to the original project objectives. The overall objectives of the project to-date have been to convert Alberta asphaltenes to mesophase pitch with a high mesophase content suitable for NCS or CIC manufacturing. Three batches of Alberta Asphaltenes with different pretreatment histories and origins were received. All samples, S1, S2 and L1 sourced from Athabasca bitumen, have already been converted into high mesophase pitches. NCS and CIC have been prepared from S2 and L1. The physical properties of these NCS films were characterized and were found to meet the criterion for their incorporation in MEAs. MEAs have been constructed from these NCS films and were tested for their fuel cell performance. The performance was quite similar to the performance of NCS films made from commercial pitch.

Performance metrics: The targeted metrics for asphaltene-derived NCS or CIC include a specific surface area of ≥200 m^2/g, a porosity of ≥80%, and electric conductivity of ≥0.5 S/cm. For the MEAs prepared from the asphaltene-derived NCS or CIC, the targets include performance at 0.8V of ≥300 mA/cm^2, hydrogen and oxygen crossover lower than 2 mA/cm^2, and the power loss of less than 10% after 30,000 catalyst durability testing cycles.

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

The methodology applied in this project is as follows.

Material preparation: Pyrolysis is used to create mesophase pitch from asphaltene, making it more resembled to the commercial mesophase pitch that used in our NCS and CIC production. NCS and CIC are prepared using either the asphaltene-derived pitch or Alberta asphaltene samples directly, following our patented procedure. Briefly, mesophase pitch serves as a carbon precursor and is carbonized to form the NCS or CICs. Platinum nanoparticles are deposited on the NCS or CIC by reducing precursors using wet chemistry methods, including wet impregnation and colloidal methods. MEAs are prepared through hot pressing using standard methods. Briefly, the Pt-loaded NCS is placed on a gas diffusion layer (GDL, Toray). Ionomer dispersion is drop-cast onto the NCS to bind it with the GDL. A PFSA membrane (Nafion or Gore) is placed over the NCS, and another commercial gas diffusion electrode with 0.2 mg/cm^2 Pt loading is placed on top. The assembly is then hot-pressed for 3 minutes.

Physical Property Characterization: The yield of mesophase pitch from asphaltene is analyzed by measuring the mass loss, the mesophase content is analyzed by polarized optical microscopy, and the softening point of the pitch is measured using an Electrothermal® melting point apparatus. The specific surface area, pore size, and pore volume of NCS and CIC are measured using nitrogen physisorption and an electrochemical method (i.e., cyclic voltammetry). The surface and cross-sectional images of the materials are characterized via scanning electron microscopy (SEM). Elemental analysis is carried out using energy-dispersive X-ray spectroscopy (EDX) and an elemental analyzer. Electrical conductivity is measured using a resistance meter. The platinum particle size is determined by X-ray Diffraction (XRD).

Electrochemical Analysis: The electrochemical surface area (ECSA) of platinum is measured via cyclic voltammetry (CV) in a three-electrode cell using a potentiostat. Both the hydrogen underpotential deposition (HUPD) and the CO stripping methods are used to measure and calculate the ECSA.

MEA Performance Measurement: The polarization curve of MEAs is measured using the DOE's polarization protocol at a test station (Scribner, Jinetics, Greenlight). Cell resistance and ECSA are measured in an MEA using the same test station through electrochemical impedance spectroscopy and cyclic voltammetry. Accelerated durability tests (e.g., square wave accelerated stress tests) are carried out following the DOE's protocol.

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

The key results of the project are summarized below.

Milestone 1: Develop NCS and CIC Using Alberta Asphaltene, achieving ≥200 m^2/g surface area, ≥80% porosity, and ≥0.5 S/cm conductivity.

1. A method has been developed to convert Alberta's asphaltenes into high-quality pitch feedstock suitable for the preparation of the novel nanoporous carbon scaffold (NCS) or colloid imprinted carbon (CIC). The temperature, heating duration, pressure and gas atmosphere of the pyrolysis process have been optimized to achieve a mesophase pitch with desired softening point (250°C – 300°C) and high mesophase content. This result is important for the scale-up process design of converting asphaltene into our value-added products.

2. NCS and CIC have been successfully produced from either Alberta asphaltene-derived mesophase pitch or the asphaltene samples directly. The NCS and CIC prepared from the asphaltene have porous structure similar to the commercial mesophase pitch derived NCS and CIC. The physical structures meet our metrics, including a specific surface area of ≥200 m^2/g, a porosity of ≥80%, and electric conductivity of ≥0.5 S/cm.

Milestone 2: Develop MEA from Asphaltene-derived NCS or CIC, achieving or exceeding DOE's MEA target.

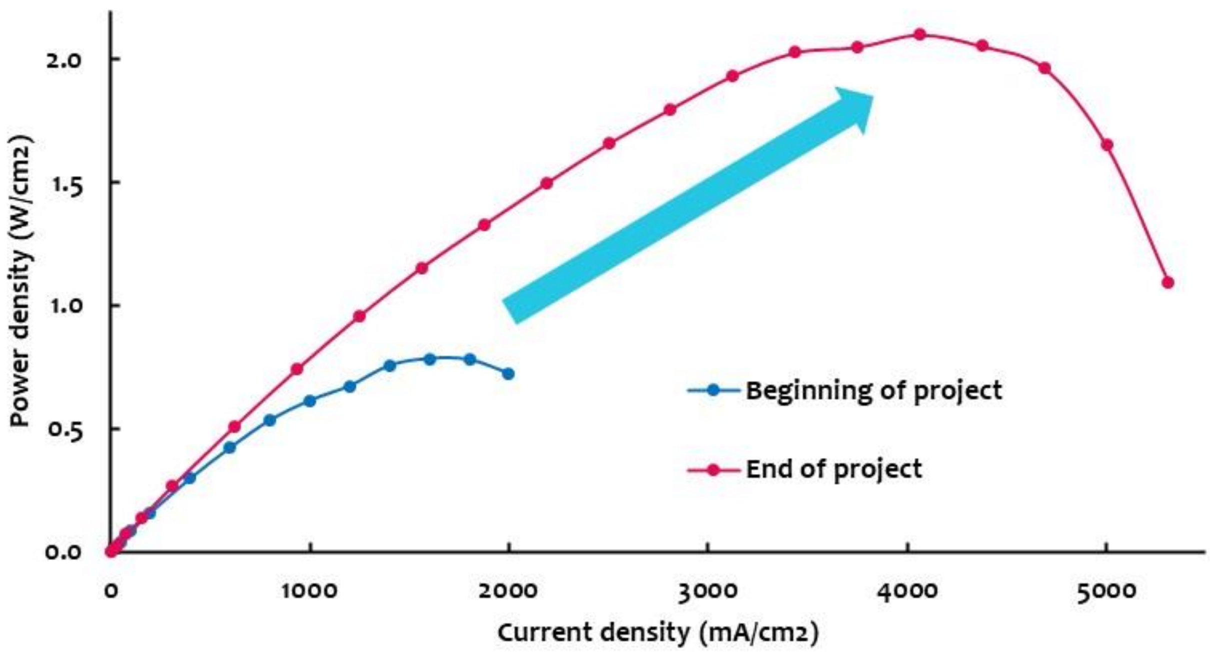
1. MEAs have been successfully prepared using asphaltene-derived NCS and CIC. The production process has been optimized to achieve our MEA goals, including Pt loading, ionomer loading, production conditions, and fuel cell testing conditions.

2. The platinum loading on the asphaltene-derived NCS has been optimized and well-controlled at 2-5 nm. Electrochemical surface area measured in three-electrode cell varies from 70 to 93 m^2/g, which is comparable and higher than many commercial catalysts for MEAs.

3. The MEA performance measured via DOE's polarization curves achieved our metrics including include performance at 0.8V of ≥300 mA/cm^2, hydrogen and oxygen crossover lower than 2 mA/cm^2.

4. The platinum durability of the as-prepared MEAs achieved the power loss of less than 10% after 30,000 catalyst durability testing cycles.

5. The MEA power density has improved from less than 1 W/cm^2 at the beginning of the project to 1.7 W/cm^2, representing a 70% improvement.



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

The key learnings during this project are summarized below.

Milestone 1: Develop NCS and CIC Using Alberta Asphaltene, achieving ≥200 m^2/g surface area, ≥80% porosity, and ≥0.5 S/cm conductivity.

Task 1: Characterize Alberta Asphaltene using SEM, TGA, elemental analyzer, and XRD

The goal of this task was to understand the physical characteristics of the received asphaltenes, in order to guide the further experimental parameters to convert the asphaltenes into pitch and further into NCS and CICs. FTIR analysis showed the aromatic content of the asphaltene samples. XRD showed the strength of diffraction peak of various asphaltene samples, indicating and predicting the most suitable samples for preparing mesophase pitch in our process. MALDI-TOFMS showed that the goal of further processing of a specific asphaltene sample will be to increase the molecular weight of the polycyclic aromatic hydrocarbons in it and to stack the polycyclic aromatic hydrocarbons into liquid crystal structures. CHNS analysis demonstrated carbon content, C/H ratio and residue content of various asphaltene samples. Based on the above analyses, the propensity of forming pitch with suitable characteristics for further conversion to NCS and CICs was determined.

Task 2: Turn asphaltene into mesophase pitch using catalytic synthesis methods.

The challenge with this task was to decide on the reaction conditions and reactor type most suitable to convert the Alberta asphaltenes to mesophase pitch. The published literature in this field was heavily relied on to decide the initial reaction conditions. The reactor type was decided after visiting labs in the Chemical Engineering Department at the University of Calgary, where petrochemical research is being done using high temperature and pressure reactors. Based on these learnings, an old reactor was modified to do the asphaltene conversion reactions at high pressure and temperature.

Task 3: Characterize the mesophase pitch, including yield, content, temperature profile, and compare with commercial mesophase

The effect of different reaction conditions including temperature, pressure, duration, and inert gas flow on the conversion of Alberta asphaltenes into high mesophase content pitch were examined. The effect of temperature in the range of 290 to 420 °C and pressures in the range of atmospheric to 75 psig on the asphaltene conversion was studied. Heat treatment studies showed the mass loss of the asphaltene samples, is inversely proportional to the yield of mesophase pitch. Increasing the temperature in a specific range was observed to increase the mesophase content and softening point. Increasing the duration of heat treatment to a specific range of hours also increased the mesophase content and softening point. However, the effect of duration was not as pronounced as the effect of temperature. Increasing the pressure from atmospheric to a specific pressure was observed to decrease the softening point. Inert gas flow during the reactions also had a significant effect on mass loss with stagnant inert conditions reducing the mass loss and thereby increasing the yield.

Based on the learnings from these experiments, we are able to optimize the operation conditions to produce pitches with the desired mesophase content and softening points.

Task 4: Prepare NCS and/or CIC using the asphaltene-converted mesophase pitch following the patented preparation procedure and optimize the process by varying the pitch content in the precursor ink

Our patented procedures worked well with some asphaltene samples and even the first attempts at making NCS and CICs were successful. These NCS produced from a specific asphaltene are currently being tested in polymer electrolyte membrane fuel cells as part of the tasks 1-4 in milestone #2, which were started ahead of schedule. Based on the results from these tests, the NCS and CIC manufacturing procedure may be further optimized if needed.

Task 5: Characterize the asphaltene-derived NCS/CIC using SEM, gas physisorption, four-point conductivity measurement, elemental analysis, etc.

The primary application of NCS and CIC will be as electrode components in an MEA of a hydrogen fuel cell. In order to work well in an MEA, the NCS/CIC should have high surface area, high porosity and good conductivity. The NCS produced from some asphaltene samples had very similar characteristics compared to NCS prepared from commercial mesophase pitch (CP-NCS). The porosity of the asphaltene-derived NCS-85 is around 80 %, also very similar to CP-NCS85. The surface area of the asphaltene-derived NCS-85 was calculated to be 270 m^2/g which is a little higher than CP-NCS85 (150-200 m^2/g). The conductivity of is 0.5 S/cm which is comparable to CP-NCS85 (0.5-2 S/cm). Hence, the NCS meets the criteria for their incorporation in MEAs. MEAs have been constructed from these NCS films and were tested for their fuel cell performance as part of tasks 1-4 in milestone #2. The performance was quite similar to the performance of NCS films made from the commercial pitch.

<u>Milestone 2: Develop MEA from Asphaltene-derived NCS or CIC, achieving or exceeding DOE's MEA target.</u>

Task 1: Load catalyst (e.g. platinum) on the prepared NCS and CIC using wet chemistry methods, and study the effects of different parameters by varying catalyst concentration, reduction temperature and NCS/CIC pore sizes.

Significant experience was gained by the personnel in handling the Alberta Asphaltene-based NCS films and in the loading of catalysts during this task. Key learnings from the results include:

(a) Precursor concentration and reduction temperature both play important roles in determining the final Pt nanoparticles. Optimizing the precursor concentration and reduction procedures leads to desired Pt particles and distribution, which significantly improves the MEA performance.

(b) NCS type (i.e. derived from which Alberta asphaltene samples) and pore sizes do not significantly influence the Pt loading, particle size, or distribution.

(c) Among all techniques, drop-casting proved to have the least manufacturing complexity for Pt incorporation in NCS and provided the best performing MEAs. All subsequent Pt incorporation was carried out using this technique.

Task 2: Characterize the Pt/NCS or Pt/CIC using SEM, TGA, XRD, EDX, and analyze the catalytic behavior in a three-electrode cell through CV, EIS, polarization curve and so forth.

Based on the optimization studies in Task 2, the following key learnings are gained:

a) XRD results presented average Pt NP crystallite sizes, which has been optimized and well-controlled at a range from 2 to 5 nm.

b) The optimum Pt particles size is achieved with a specific solvent volume.

c) The optimum reduction temperature is achieved with a specific temperature.

Task 3: Prepare a membrane electrode assembly using the Pt/NCS or Pt/CIC with optimal catalyst loading and behavior. Varying the ionomer loading amount.

Significant experience was gained by the personnel in handling the Alberta Asphaltene-based NCS films and preparing MEAs during this task. More than 60 MEAs were fabricated using Alberta Asphaltene-based NCS films. Key learnings from this task include:

a) MEA performance is influenced by multiple factors, including the Pt loading, ionomer amount, sealing, NCS or CIC type, fuel cell testing conditions, and so forth.

b) The best performance so far is achieved with specific Pt loading and I/C ratio.

c) Graded NCS with optimized preparation procedures and testing conditions consistently meet DOE's targets, including the performance at 0.8 V achieving 300 mA/cm^2 and power density achieving 1.2 W/cm^2.

d) While the fuel cell performance measured by polarization curves continuously meets the DOE's targets, the ECSA data do not show correspondingly high results, which could be due to the location of Pt deposition within the NCS.

Task 4: Test the MEA under a fuel cell test station, collecting polarization curves, CV and accelerated durability cycles.

More than 60 MEAs were fabricated using Alberta Asphaltene-derived NCS films, and their performance was tested. During the initial phases of this project, the focus was on a specific asphaltene sample-derived NCS monolayer cathodes, i.e. NCS-12 or NCS-85. The performance targets could not be achieved at this stage due to low catalytic activity and high ohmic resistance in the MEAs. Catalytic activity has been improved by optimizing the Pt loading procedures and the Pt NP size has been reduced from 12 nm at the start of the project to 2-5 nm towards its end. Ohmic resistance of the MEA has been reduced by employing a thinner ionomer membrane with lower resistance. The combination of these changes and improved personnel skills helped enhance MEA performance to meet the targets.

MEAs made with asphaltene-derived NCS-12 monolayer cathodes performed well and met the performance targets, as did MEAs made with asphaltene-derived graded NCSs. This indicates that the catalytic activity, ohmic resistance and the mass transport resistance of the Alberta asphaltene-based NCS electrodes all met the performance requirements. Additionally, MEAs made with a specific asphaltene-based NCS12 and graded NCSs met the gas crossover targets, demonstrating that the MEAs made with Asphaltene-based NCS are robust and comparable to commercial MEAs.

The durability improvement is primarily attributed to the refinement of Pt NP sizes and distribution within the NCS. If Pt is well-deposited within the pores, its durability is likely to be higher due to the protection afforded by the NCS pores.

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

Project Outcomes and Impacts: The results from the project confirm the viability of converting Alberta asphaltene into value-added nanoporous carbon powder and scaffold. The MEA performance further confirms the promise for hydrogen fuel cell applications using asphaltene. The process optimizations achieved in this project will assist Momentum Materials in designing the scale-up process for NCS or CIC production, platinum loading, and MEA production. Additionally, the availability of Alberta asphaltene could potentially reduce NCS production costs, as Alberta asphaltene is estimated to be 70% cheaper than commercial synthetic mesophase pitch.

Clean Energy Metrics: The TRL level of our technology increased from 2 at the beginning of the project to 6 by the end. We are preparing one paper and assessing the possibility of filing a patent to protect the results. Two master's students and one undergraduate student were hired during the project and are now well-trained to work on the technology and other energy related technology. No emissions have been reduced since the products have not yet been commercialized. One collaboration has been formed with an automotive manufacturer in Asia to test our nanoporous carbon product. Three lab R&D positions have been created for this project.

Program Specific Metrics: There is one fuel cell manufacturer in Asia that is heavily involved in our product development, as they are our potential customer. We have initiated a project with an e-bike manufacturer to integrate our MEA into their fuel cell stacks for powering e-bikes. This e-bike project is ongoing, and we will need to scale up our MEA to a size suitable for a 100 W fuel cell stack within six months. With a manufacturing partner, we now have access to equipment capable of producing 100 grams of NCS and CIC. Momentum Materials has built MEA manufacturing capacity with NGen from 2022 to 2023, and with this capacity, we expect to be able to manufacture a 100W fuel cell stack by 2024. The ordered-structure MEA has been developed and validated in this project, and we plan to scale it up in size.

Project output: One journal article is currently under draft. Momentum Materials exhibited at the N3 Summit in Toronto and at the FC Expo in Tokyo with the Canadian Hydrogen and Fuel Cell Association, both in February of this year. Arlene will be presenting at Inventure$ in May 2024 in Calgary, discussing the Bitumen Beyond Combustion project.

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

The benefits achieved in this project are summarized below.

Economic: Momentum Materials has created three R&D-related jobs since the start of the project and has trained two student interns. We have generated increasing sales year over year the past three years representing fast-growing business activity and interest in our products. In addition to hydrogen fuel cells, our nanoporous carbon materials have attracted interest from lithium-sulfur batteries and medical catalyst substrates producers. We aim to grow our annual sales to above $3 Million in 2028 and then to more than $10 Million in 2030.

Environmental: This project marks a step forward in the utilization of our ordered-structure MEA for hydrogen fuel cell applications, including long-distance and heavy-duty transportation as well as stationary uses. Although we have not achieved emission reductions during this project, the success of our ongoing collaborations with customers and the upcoming scale-up of our MEAs will contribute to global net-zero emissions goals. By integrating our high-performance and durable MEAs into end applications and replacing internal combustion engines with clean fuel cells, we anticipate significant environmental impacts. It is estimated that if Momentum Materials Solutions powers 1,000 hydrogen fuel cars in 2025 and increases sales to 1,000,000 fuel cell cars by 2030, it could reduce Canada's annual CO_2 emissions by 2% in 2030.

Social: Since the inception of this project, we have received significant interest not only from investors but also from local oil and gas companies looking to increase the value derived from their by-products. Momentum Materials has been featured at various trade shows, representing strong and innovative Alberta SMEs. We believe that the success of this project will draw more attention to Alberta asphaltene and its potential applications in clean energy.

Building innovation capacity: We have built a lab in Bearspaw, Calgary that is capable of material manufacturing, MEA production, and testing. Our company has hired three PhDs and two Master's degree holders for product development, all of whom have now gained substantial experience in their specific tasks. Among the HQPs, one was hired from Vancouver, and another is a recent graduate from the University of Toronto, demonstrating Alberta SMEs' attractiveness to out-of-province talent. Momentum Materials attended a career fair in Boston, meeting with students from MIT, Boston University, and Harvard. We received much positive feedback and interest from students considering relocation to Calgary.

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

After this project, we will continue to optimize Alberta asphaltene-derived NCS and/or CIC for hydrogen fuel cell applications. Our next step is to scale the MEA from 1 cm² to 25 cm² in 2024. We will seek appropriate manufacturing techniques to load Pt and ionomers onto larger NCS films and optimize the Pt loading and MEA manufacturing process to maintain performance in larger MEAs. Our goal is to complete an MEA prototype using asphaltene-derived NCS-based MEAs for pilot testing with our customers.

In 2024, we aim to complete MEA production for a 100 W fuel cell stack to demonstrate our MEAs in with a customer in the transportation sector. In 2025, we plan to scale our production to 500 kW of MEAs for customers in long-distance and heavy-duty applications, which will generate $174,000 in revenue from the asphaltene-derived MEA. The scale-up to 500 kW will require scaling up production of the asphaltene-derived NCS, Pt loading equipment, and optimized MEA production and sealing processes. By 2028, we aim to scale our production to 10,000 kW for various hydrogen fuel cell applications.

We aim to maintain our collaboration with existing customers in the hydrogen and transportation sectors. We will actively seek new partners and customers for product development and pilot testing to achieve our commercialization goals.

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

The knowledge gained from this project will be disseminated through the publication of a paper and technical presentations at various conferences.

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 project began with the objective of converting Alberta asphaltene, an oil and gas byproduct, into high-value nanoporous carbon materials for hydrogen fuel cell applications. The proposed process involves converting the asphaltene into mesophase pitch, a carbon precursor, and then producing our proprietary nanoporous carbon materials, including nanoporous carbon scaffold (NCS) and colloid-imprinted carbon

(CIC). The prepared NCS and CIC are loaded with platinum and used to manufacture MEAs with other components sourced from reliable suppliers.

In the first year, we developed and optimized the method for converting asphaltene into mesophase pitch with a desired softening point (250-300°C) and high mesophase content. We successfully prepared NCS and CIC from the asphaltene samples, and these materials achieved our targeted surface area, porosity, and electrical conductivity, demonstrating properties similar to those prepared from commercial mesophase pitch.

In the second year, we optimized the platinum loading, ionomer loading, and the MEA production process, successfully producing high-performance and durable MEAs from asphaltene-derived NCS and CIC. The platinum particle size is controlled between 2-5 nm, and most of the platinum is deposited within the pores. The MEA performance meets multiple DOE MEA targets, and the durability is outstanding compared to commercial MEAs.

We have obtained many key learnings from the project, including how to make mesophase pitches from asphaltene, how to improve catalyst and ionomer loading in MEAs, and how to achieve desired performance by optimizing factors surrounding MEA production and fuel cell operation. These key learnings and outcomes will assist us in future scale-up production of asphaltene-derived NCS, CIC, and the derived MEAs.

We have benefited from this project by gaining valuable knowledge and generating new intellectual property (IP). There are multiple economic, social, and environmental benefits that have emerged from this project. The results are promising, and we have obtained many collaborators and investors who have faith in our continued development of this technology.