The Bowman Centre
For Sustainable Energy

Queen’s University Technology, Engineering, and Management (TEAM)

Technology, Engineering and Management (T.E.A.M.) is a multidisciplinary project course offered by the Department of Chemical Engineering at Queen's University that connects students (science, engineering, and business) with companies seeking additional consulting resources. Since 1995, T.E.A.M. provides participating companies with a unique opportunity to gain valuable business and technological insights for a modest investment. These reports could not have been accomplished without the collaborative efforts of those who helped organize the program at Queen’s University and the Associates of the Bowman Centre for Sustainable Energy.

2017:

Project Title: **Adding Value to Bitumen**

Project team: Anna Rhamey (Chemical Engineering), Michael Burch (Chemical Engineering), Jaynesh Mistry (Chemical Engineering), Sydney Olsen (Chemical Engineering)

Queen’s advisors: John Carlson, David Mody, Oxana Shibaeva, David Sask.

BCSE advisors: Ed Brost, John Ward

Abstract:

Introduction

The introduction serves to provide the reader with an understanding of the problem that the Bowman Centre for Sustainable Energy (BCSE) –T.E.A.M. Joint Venture set out to solve.

Candidate Materials

This section provides an outline of candidate materials under consideration throughout the study. This section also outlines the screening approach as executed throughout the rest of the report.

Preliminary Screening

This section considers all products as listed in the candidate materials section. Phase 1 employs a technical, economic, and socio-environmental evaluation to determine the materials best suited to BCSE’s objectives. These top candidate materials are assessed in detail in Phase 2 of the study.

Market Overview

The preliminary screen includes a top-level overview of product markets, describing key driving forces for each market, and stating the end to end supply chain of each market.

In-Depth Feasibility Assessments of Commercial Opportunities

The feasibility assessment is three-pronged, considering market opportunity, technical feasibility, and economic viability of the candidate materials. The section is sub-divided into market, technical, and economic sections for further clarity. Weighted evaluations allow for the market, technical process, and economic model's opportunity to be quantified such that a comprehensive, prioritized list of candidate materials results.

Recommendations

Recommendations made based on results of feasibility assessments, and an action plan for the Bowman Centre for Sustainable Energy to further pursue and develop the opportunities identified by the TEAM group.

To discuss this project or obtain a copy of the final report (a fee is required) please contact mkern@bowmancentre.ca

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2018:

Project Title: **Producing Carbon Fibre from a Barrel of Pitch**

Project team: Claire Wilson (Process Chemical Engineering), Adam MacEachern (Biochemical Engineering), Siri Lake (Biochemical Engineering), Ravin Lee (Process Chemical Engineering)

Queen's advisors: Dave Mody, Ashwin Gupta, Peter Renaud

BCSE advisors: Ed Brost, John Ward

Abstract:

The Bowman Centre for Sustainable Energy was seeking a non-combustible use for pitch produced by the Canadian Alberta oil sands. It was essential that this alternative application consumed high volumes of pitch to offset the potential impact on the value of bitumen resources as a result of the de-carbonization of Canada's economy. However, it was vital that this alternative approach to using Canada's bitumen did not produce added emissions as a byproduct. With that, this report explored the possibility of converting bitumen pitch to carbon fibre. While processes exist for converting petroleum-derived pitch, these are less common than more conventional feedstocks and have not been universally successful. Such alternative methods of producing carbon fibre have process details that are highly proprietary. This report investigated the growing demand for carbon fibre across major industries including aerospace, automotive, wind energy, and construction. In doing so, it was determined that the automotive sector is likely to be a key future market due to its potentially high-volume demand for standard modulus carbon fibre. A market analysis of the automotive sector was then conducted to evaluate the opportunity for pitch-derived carbon fibre to become a staple in lightweight automotive manufacturing material.

Several alternative methods to produce standard modulus carbon fibre were studied and a finalized process was determined through the stepwise evaluation of unit operations. The final process steps that are recommended to produce standard modulus carbon fibre at a rate of 2,250 tonnes/year are as follows:

1. *Pitch pre-treatment via nitrogen bubbling at 450˚C to improve the quality of the feedstock.*
2. *Oxidation oven heat treatment at 250˚C for up to 2 hours.*
3. *Low temperature furnace heat treatment at 1000˚C. Residence time to be determined through experimentation.*
4. *High temperature furnace heat treatment at 1500˚C. Residence time to be determined through experimentation.*
5. *Surface treatment through a refluxing nitric acid bath followed by chemical rinsing and resin addition.*
6. *Winding of finished product (in mat or individual fibre form) and preparation for shipping.*

The chemical changes, fate of the heteroatoms, and process technologies were studied to develop a process flow diagram and accompanying heat and mass balance. Since much of the information is proprietary in nature, it was determined that further experimentation would be required to confirm assumptions that were integral to the design of the process. Specific areas of focus for future research by the BCSE should be centered around pitch pre-treatment and surface treatment of the carbon fibre product.

Given the finalized process, an economic analysis was conducted to determine that the prospective plant would require a capital investment of $66 million and have an annual operating cost of $20 million (based on the low bound CAPEX estimate). With that, it was determined that the optimal selling price of carbon fibre was $26.60 CAD/kg, which would accomplish a payback period of 10 years with a discount rate of 30%. However, given that this was the low bound (battery limits) estimate, a RAND analysis was conducted to assess what the high bound CAPEX of development would be. Through this, it was determined that a RAND factor of 2.62 most accurately accounted for the excluded costs, and resulted in an high bound CAPEX estimate of $170 million. For this capital cost to be paid back in 10 years with a 10% discount rate, carbon fibre must be sold at a unit price of $37.85 CAD/kg assuming that 2250 tonnes are produced and sold annually. Finally, it was important to note that if a target price of $13.34 CAD/kg could be achieved, demand for carbon fibre would dramatically increase to over 138,000 tonnes/year, making this price point a definite benchmark for the future.

Overall, converting pitch to carbon fibre presented itself as a technically feasible, but not yet economic, strategy to provide the Alberta oil sands with a sustainable future. Entering this market is an opportunity to diversify Canada's economy, and should continue to be pursued. After the recommended experimentation is conducted, there will be a more complete *understanding of the process parameters and associated costs such that the project can move towards implementation and commercialization.*

To discuss this project or obtain a copy of the final report (a fee is required) please contact mkern@bowmancentre.ca

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2019:

Project Title: **Carbon Fibre from Oil Sands Bitumen & Other Feedstocks; A Comparative Lifecycle Assessment**

Project team: Nick Bichel (Process Engineering), Megan Bischoff (Chemical Engineering), Ryan Ingham (Process Chemical Engineering), Karen Lee (Finance), Emily Varga (Biochemical Engineering)

Queen's advisors: Ashwin Gupta, Peter Renaud

BCSE advisors: Ed Brost, John Ward

Abstract:

The TEAM project on Comparative Green House Gas (GHG) Life Cycle Assessment (LCA) of Carbon Fibre from Oil Sands Bitumen vs. Other Feedstocks was completed for the Bowman Centre for Sustainable Energy (BCSE). This report is a continuation of a study by the BCSE to use bitumen resources in a less GHG intense way by manufacturing a durable product, namely carbon fibre, instead of producing a combustible product. This comparative study assesses the overall GHG emissions for two pathways of producing carbon fibre. The first being through the use of Polyacrylonitrile (PAN), the typical carbon fibre precursor, while the second use being bitumen-based pitch, an alternative precursor identified in last year's TEAM Project. Each precursor is derived through a specific pathway of chemical processes that begin with extraction of crude oil but differ in the subsequent steps to produce carbon fibre. The following document serves as the final report to communicate the scope, assessment, and final recommendations on the project.

Detailed research on the carbon fibre manufacturing process, LCA methodology and accounting standards were used to complete the GHG assessment of the two processes. GHG emission data for each process step and the transportation between processes was collected from LCA databases and literature. Using the yields between each process stage, a cumulative GHG intensity for each pathway was developed. It was determined that the overall GHG emissions for the PAN pathway is approximately 81 kg CO2e/kg of carbon fibre. For the bitumen pathway, total emissions of 7 kg CO2e/kg of carbon fibre was calculated. The bitumen pathway has a significant advantage in terms of GHG intensity for producing carbon fibre. However, this analysis was done based on a heavy oil feedstock such as that from the Canadian Oil Sands. Recognizing that this is not a typical pathway to producing carbon fibre via the PAN precursor, a conventional light oil feedstock was assessed. It was seen that using

a conventional light oil feedstock reduces the GHG intensity of the PAN pathway by over 60% to approximately 35 kg CO2e/kg of carbon fibre but does not change the conclusion of the assessment.

The emissions advantage of the bitumen pathway over the PAN pathway would likely lead to advantages in carbon pricing regulations. Thus, regulatory surcharges associated with the two rival pathways, under the carbon pricing schemes currently imposed in Ontario, Alberta, and European Union were investigated. Key findings included the potential exemption of a standalone bitumen-based carbon fibre plant from carbon pricing, under certain jurisdiction. Given the LCA findings, a standalone bitumen-based plant could produce 11.4 times as much carbon fibre annually as its PAN based carbon fibre, before being categorized as a large industrial emitter in Ontario and Alberta. As a result, a bitumen-based commercial level carbon fibre plant may only have to comply with the carbon pricing regulations applied to consumers and small businesses.

The bitumen pathway can be further improved in terms of GHG intensity by leveraging new and developing technologies such as a more sustainable methods of crude oil production. The process can also benefit by using more electricity-based unit operations rather than natural gas, for process steps based in low GHG intense electricity production areas such as Ontario. Overall, converting bitumen to carbon fibre is a less GHG intense method than the typical PAN pathway, providing Canada with an opportunity to use bitumen resources in a more sustainable way.

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2020:

Project Title: (DRAFT) **Analysing Pre-Treatment Processing in Manufacturing Carbon Fibre Precursors From Bitumen**

Project team: Patrick Taylor (Chemical Engineering), Sarah (Sijing) Li (Chemical Engineering), Andrew McColl (Commerce), Ellie Kenny (Chemical Engineering)

Queen’s advisors: Ashwin Gupta

BCSE advisors: Ed Brost, John Ward, Peter Smith

Abstract: *to be determined; project completion scheduled for April 2020.*

To discuss this project or obtain a copy of the final report (a fee is required) please contact mkern@bowmancentre.ca