The Bowman Centre
For Sustainable Energy

CANADA: Evaluating Three Nation-Building Projects

A Project of

The Bowman Centre for Sustainable Energy

Released November 2021 Concurrent with

The Third Richard Marceau Energy Symposium

Which is a collaboration with IEEE Canada Toronto Section,

Canadian Academy of Engineering, and

Canadian Society of Senior Engineers

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The Bowman Centre for Sustainable Energy is a federally-incorporated non-profit organization, with volunteer Associates who have lived and worked across Canada. In the spirit of peace and friendship, we honour the Anishinaabek of the Three Fires Confederacy, on whose traditional territory our office is located.

Introduction

For over a decade, the Bowman Centre for Sustainable Energy has promoted Canada as a sustainable energy superpower. This theme is articulated in our early publications edited by Dr. Richard Marceau and Dr. Clem Bowman.

CANADA: Winning as a Sustainable Energy Superpower (2012)

> "As the world begins its slow transition to non-carbon-based energy resources, Canada is in a position both to serve carbon- and non-carbon-based energy resource needs in an environmentally responsible manner, which may not be the case elsewhere.
>
> The Canada we know has been created by big projects in transportation, communication and energy, initiated by visionaries who overcame enormous obstacles.
>
> We urge Canada to take action in specified areas, recognizing that these actions will require dedicated private and public sector partnerships of the type that characterized previous big projects that have defined the nation."

CANADA: Becoming a Sustainable Energy Powerhouse (2014)

> "Our planet faces two civilization-changing challenges in this century: access to energy by the 2 billion people who have limited or no access to energy, and climate change. With Canada's unique endowment of energy sources, both renewable and non-renewable, the nation has the capacity – some would say the responsibility – of contributing to the resolution of both of these challenges. To provide greater opportunity to its people and strengthen its long-term financial sustainability, Canada has an additional major challenge; that of capturing greater value from its natural resources by upgrading them to higher value products, thus capturing added wealth and jobs."

CANADA: Making the Case for Nation-Building Projects (2019)

> "Canada needs a *'vision of the possible'.* A clear plan, driven by visionary and courageous leaders to implement Big Nation-Building Projects with far-reaching benefits. We need Big Projects in the same nation-building scale as the Canadian Pacific Railway, the St. Lawrence Seaway, or the Trans-Canada highway."

In our prior publications we have described a number of successful Big Projects that continue to generate the wealth Canada needs to enjoy our quality of life. These Big Projects allow Canada to be consistently recognized as one of the best nations on earth. We put forward that Big Projects require a time-frame from start to completion that is beyond the usual term of a government, or the tenure of the CEO of a company. Further, the financial resources to be committed to bringing a Big Project to completion are beyond the capacity of most companies. This necessitates risk-sharing such as with various levels of government, or a consortia of enterprises. It is also clear to us, and should be clear to all Canadians, that Big Projects require active collaboration with stakeholders such as First Nations.

The question and challenge remains: how can we now achieve success and deliver a big energy project with these criteria? We posit that visionary leadership is required.

Across Canada we can see that our existing energy system was built under different oversight and ownership models, whether Federal or Provincial, via a crown corporation or open market, inter-connected or independent. We can also see that energy generating capacity as well as the transmission systems (electrical lines, rail, highway, pipeline, or ship) have been built for different purposes. Some energy capacity and transmission is for a domestic market, some for an export market, and some for downstream users of the energy (such as an aluminum smelter). Throughout these disparate lenses, we can see three energy system chains.

The following flowchart shows that Canada has electrical resources in abundance. Biomass, wind power, photo-voltaic solar power, nuclear power, tidal capacity, hydro-electric power, and natural gas thermal generation are available in Canada. We note that coal-fired thermal generation exists, and will be phased-out.

The flowchart also shows Canada's abundance of hydrocarbon resources. There is extensive infrastructure across Canada supporting the current uses of hydrocarbons.

Finally we have added to the flowchart the opportunity for energy storage, and hydrogen as a carrier or store of energy.

Now we need to show how Canada can depend on these three energy chains to move forward to a sustainable energy future.

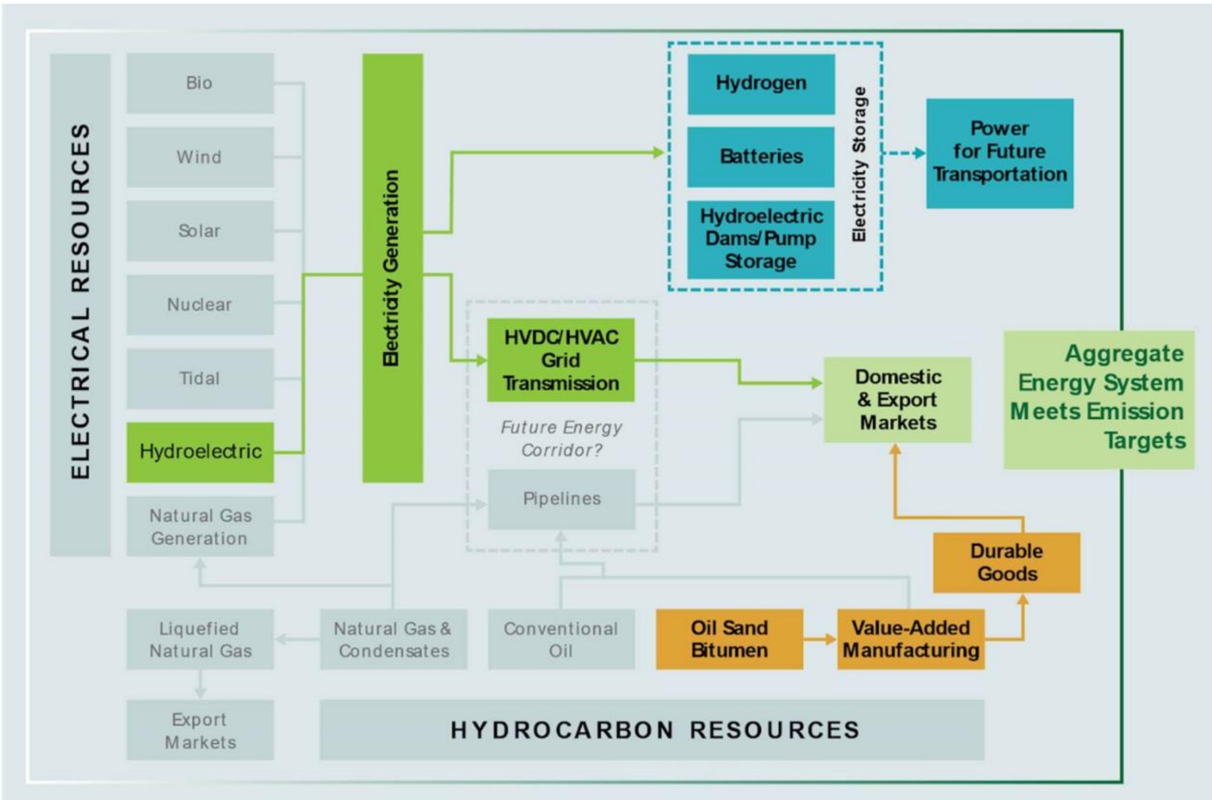
We determined in 2020 that we, the Associates of the Bowman Centre for Sustainable Energy, needed to take action. We assembled several teams of our Associates to adopt the role of visionaries. Each team developed a description of an Opportunities aligned with each of the three energy system chains.

Using the structured decision-support methodology of ProGrid® we prepared specific evaluation criteria using environmental, economic, and social aspects. Then we reached out and engaged others to expand our evaluations. Our analysis of the three Opportunities, the big nation-building projects, show a path for Canada to a sustainable energy future.

Now is the time for us to deliver this report.

Our next steps will be to identify visionary proponents for these nation-building projects. We will support those visionaries by using our evaluations to guide success for the next Big Projects.

In the following figure from Bowman Centre for Sustainable Energy's report "CANADA: Making the Case for Nation-Building Projects", three Canadian energy system chains were highlighted for attention.

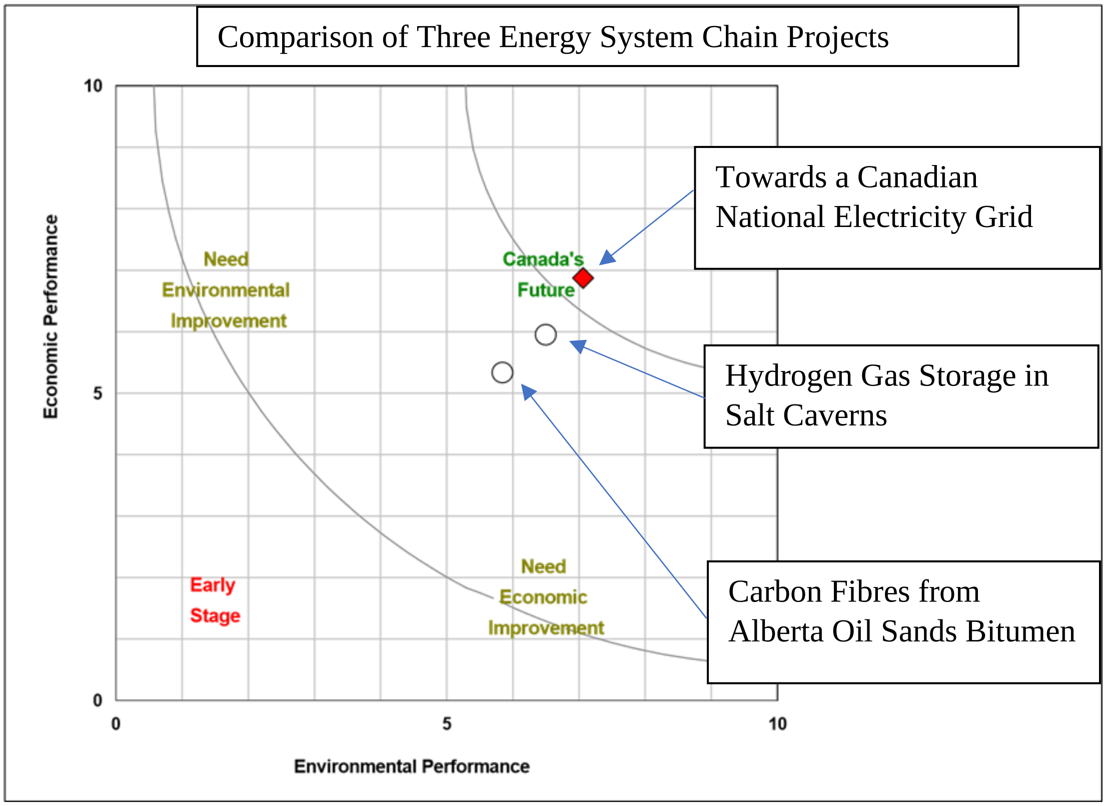


The Bowman Centre for Sustainable Energy has prepared three example nation-building projects; each project aligns with one of the three energy system chains. The ProGrid® Evaluation Methodology has been used to further examine the potential of these energy chain projects. The projects are:

1. "Towards a Canadian National Energy Grid" (Darker Green boxes in above chart) - Collection of Canada's electrical generation capacity into a national grid for distribution and use in domestic and export markets.
2. Hydricity, specifically: "Hydrogen Storage in Salt Caverns" (Blue boxes in above chart) - Gradual introduction of hydrogen into a two-currency energy system composed of hydrogen and electricity, to meet the needs for the expected expansion of electrical cars.
3. "Carbon Fibres from Alberta Oil Sands Bitumen" (Light Brown boxes in above chart) - Transition in the use of oil sands bitumen from fuel for gasoline powered engines to a feedstock for the manufacture of value-added durable goods based on carbon fibres.

A key advantage of the ProGrid® methodology is a visual representation of the evaluations with consideration of the strength of each project versus the overarching criteria of Economic Performance and Environmental Performance. The goal is to identify and support projects that can deliver results in the upper-right quadrant, where Canada's sustainable energy future lies.

The following graph shows the positions of the three energy system chain projects with respect to achieving Canada's sustainable energy future.



All three projects can contribute to Canada's sustainable energy future. The project "Towards a Canadian National Electrical Grid" is closest to delivering the benefits needed to move Canada to the upper right-hand corner – the position of Canada's future sustainable energy state.

The project "Hydrogen Gas Storage in Salt Caverns" can contribute to Canada's sustainable energy future. As will be discussed later, there are concerns about the ability of this project to contribute on a national scale.

Finally, the project "Carbon Fibres from Alberta Oil Sands Bitumen" has greater uncertainty than the other projects. Still, it is seen as a contributor to Canada's environmental and economic performance.

The Mission of the Bowman Centre for Sustainable Energy

The mission of the Bowman Centre for Sustainable Energy is to catalyze big energy projects which drive Canada's energy strategy and generate economically and environmentally sustainable wealth and jobs.

We have undertaken this series of evaluations to further our mission.

Short history of Big Projects and contributions to Canada's wealth.

Canada has undertaken numerous significant, large-scale projects since Confederation, mainly in the areas of transportation, communications, and energy. The research and commentary that the Bowman Centre for Sustainable Energy has published shows that these successful projects changed the economics for all future projects, and for the nation as a whole.

New big projects can continue this tradition with emphasis on sustainable development and a higher level of upgrading our energy resources into value-added products.

Since 2020, Associates of the Bowman Centre for Sustainable Energy have developed feasible scope statements for three energy system chain projects. We have completed evaluations of these projects using ProGrid® technology. We have solicited and received evaluations from members of the Canadian Academy of Engineering, the Canadian Society of Senior Engineers, and the C2C2C Unity Corridor.

This report presents the scope of the projects, the result of the many evaluations, and a path forward to a sustainable energy future for Canada.

The Three Big Projects:

Associates of the Bowman Centre for Sustainable Energy volunteered to participate on three teams. They performed the role of being visionaries for Canada's sustainable energy future. Each team prepared, debated, and settled on a clear description of a big energy project that represents one of the energy system chains. What follows are the three final project descriptions that were used for the ProGrid® evaluations. Within the ProGrid® methodology, each project description is treated as an 'Opportunity'.

Big Project – Opportunity – **Towards a Canadian National Electricity Grid**

The global transition from fossil fuels to low-carbon renewable energy is underway. Driven primarily by simple economics, the ground transportation industry is set to transition to electric vehicles over the next decade or two, to be followed by shipping and air transportation and finally space heating. This transition will require not only the replacement of the approximately 20% of Canadian electricity that comes from fossil sources, but also around an additional 50% capacity to replace the energy currently supplied by oil and gas (assuming the use of conservation and new technologies). Where will Canada get this energy and how will we get it to the cities and load centres that need it?

In the past, each province sought to optimize its energy resources to meet its own electricity needs, but today we need to think nationally to ensure we make the optimal use of those resources. Ten provinces and three territories need to think and act as one nation, because together we can find solutions that benefit us all. Pooling energy resources to meet the common need for low carbon energy we benefit from more constant blended load profiles, by differing intermittent generation capabilities, by energy storage opportunities and by premium priced clean energy exports.

Rather than enjoying strong inter-provincial transmission ties and sales, we typically have stronger ties with the United States than we do with each other. While we will want to make use of these N-S ties for energy exports, we first need to ensure that we have sufficient low cost electricity to meet our domestic needs and we can bring the renewable energy in from any point of generation to meet those export sales.

Dwight Eisenhower was credited with saying something to the effect of "Plans are Useless but Planning is Essential", by which he meant that the future is unknown and our first assumption may be proven wrong quickly rendering our plan useless, but having planned and having an overall objective in mind we can quickly adapt to the new circumstances and still reach our goal. What Canada needs today is a plan of how we can unite our country, so that, having planned, we will be able to adapt our plan to whatever the future brings.

We start by designing a national grid that unites our existing provincial systems and provides a way to connect our untapped resources to our cities, load centres and international customers. We look at how and where to best make those connections and then we build nothing. Nothing, until we determine where the economic opportunities lie, and then we build only those parts that make sense. So that, piece by piece, we connect the provinces together and with each piece we build a part of that greater system that we planned and we enable even further economic opportunities and growth. It may take decades before we can truly say that we have an East-West electricity transmission system, but that will never occur without a plan.

The Opportunity was assessed by 15 Evaluators.

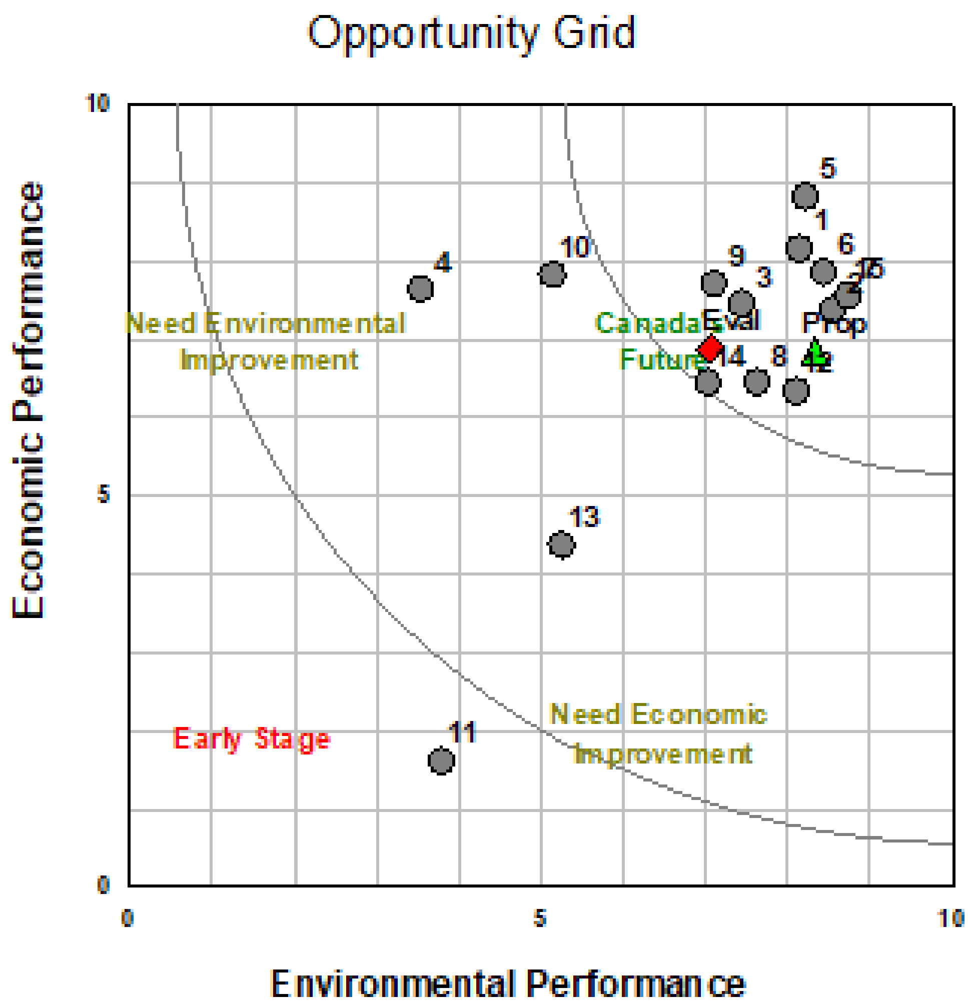
The following graph shows the evaluated Opportunity position as determined by the Proponent, each Evaluator, and the Evaluator Average, with respect to the two Overarching Objectives of Economic Performance and Environmental Performance.

The Opportunity ratings have the following characteristics:

Economic Performance = 6.9

Environmental Performance = 7.1

R Value = 70% *(The R Value is a measure of the distance of the Evaluator average grid position for the Opportunity towards to point 10,10)*



Big Project – Opportunity – **Hydrogen Gas Storage in Salt Caverns**

Large scale, economic energy storage is the holy grail for non-dispatchable renewable energy, a pre-requisite to ubiquitous deployment of renewable energy infrastructure. Large-scale storage schemes are under development and some currently in utility scale use. The latter includes pumped storage for hydro-electric generation. Others include compressed air storage, liquid air storage, chemical batteries, large fly-wheels and others including hydrogen storage.

Our most energy dense, on a mass basis, (Joules/kg) non-nuclear material, hydrogen, presents challenges because on a volumetric basis, hydrogen is our least energy intense material (Joules/L). Compressing hydrogen to pressures making stored hydrogen practical requires expensive compressors and storage vessels. Metal hydrides are in development but not yet practical. Liquifying hydrogen is costly. So far liquid hydrogen is limited to NASA and their counterparts. While storing hydrogen is challenging, manufacturing it is not.

Technology to produce hydrogen is well established. But once manufactured, hydrogen's properties make storage in significant quantities challenging. However, there are a few operational examples in other parts of the world where hydrogen gas is stored in salt caverns. Could salt caverns be used to store hydrogen in Canada?

Hydrogen storage in salt caverns may offer many regions in Canada an opportunity to play a leading role in energy storage. That role could play out as regional utility scale hydrogen production, storage and conversion back to electricity. Think of this mix of equipment as a battery. Hydrogen from this cavern-based battery could be also used as a fuel for heating as well as a chemical feedstock for manufacturing.

Salt caverns exist in numerous regions across Canada, primarily to store hydrocarbons. However, for purposes of this exercise wells in the Sarnia – Lambton region of Ontario were used to evaluate this concept.

South-Western Ontario's geology includes deep underground salt veins. These veins have been solution mined to produce safe underground caverns for storing a variety of fluids. Preliminary analysis of the opportunity to use caverns to store utility scale volumes of hydrogen looks promising. Salt Cavern volumes in South Western Ontario range from about 10,000m3 to about 250,000 m3. Current in-service salt cavern storage in the Sarnia to Windsor region totals about 3.5 million m3.

A typical Sarnia Lambton cavern has a working volume of about 30,000m3. At working pressure (~700 m brine head) such a well could store about 200 tonnes of hydrogen gas. That gas would hold about 28,000 GJ (HHV) and at combined cycle turbine efficiency of 50% (or fuel cell) almost 5,000 MW-hrs could be recovered as electricity from that 200 tonnes. Recovering this energy over a ‘peak demand’ window of 10 hours translates into a fuel supply for a nameplate 450 MW device. From one small storage cavern.

An engineering and economic analysis of this proposal is underway by Queen's University students as a Capstone project. Their report was received in the spring of 2021.

If the economics can be made to work then large-scale storage of hydrogen should be able to help balance, or peak shift and load follow electricity demand. This would enable larger deployment of wind and solar generated electricity across Canada for domestic as well as export markets.

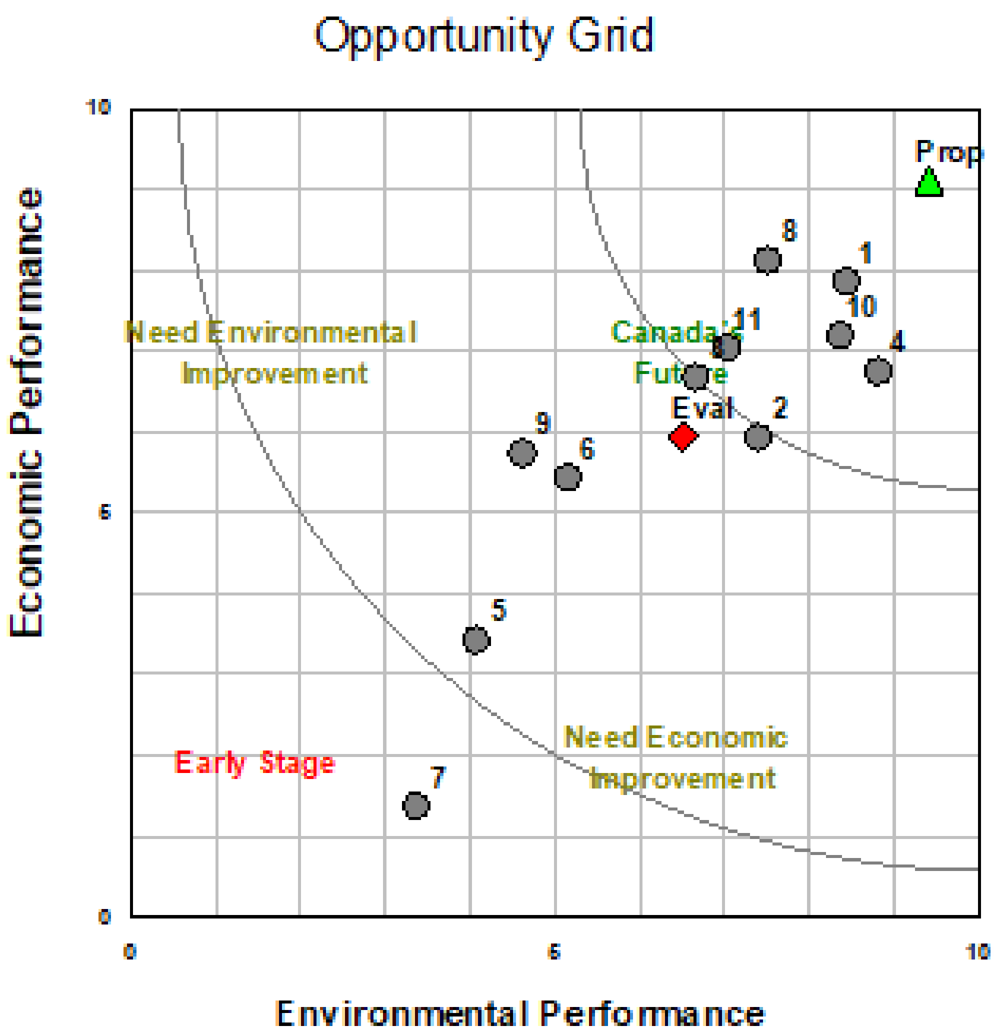
Finally, the technology risks for this project are minimal. Hydrogen manufacture using electrolysis is well established and efficiency improvements continue to occur. Salt caverns are already being used to store hydrogen in a few places around the world. The Ontario Ministry of Natural Resources has given a preliminary opinion that salt bed geology in south western Ontario is suitable for hydrogen gas storage. Transport of hydrogen by pipeline to local and distant markets has been practiced for many years. Conversion of hydrogen to electricity is also proven as well as for heat loads. There is no technology risk associated with this proposal.

If hydrogen storage were to be developed on a demonstration scale in Sarnia-Lambton this region could lead the way for a national scale energy storage system.
http://energystorage.org/energy-storage/technologies/hydrogen-energy-storage

The Opportunity was assessed by 11 Evaluators.

The following graph shows the evaluated Opportunity position as determined by the Proponent, each Evaluator, and the Evaluator Average, with respect to the two Overarching Objectives of Economic Performance and Environmental Performance.
The Opportunity ratings have the following characteristics:

Economic Performance = 5.9
Environmental Performance = 6.5
R Value = 62% *(The R Value is a measure of the distance of the Evaluator average grid position for the Opportunity towards to point 10,10)*



Big Project – Opportunity – **Carbon Fibres from Alberta Oil Sands Bitumen.**

Carbon fiber is considered an advanced material due to its tensile strength to weight ratio, electrical and thermal superconductivity. The majority of carbon fiber today is manufactured from polyacrylonitrile (PAN), a synthetic polymer resin that has undergone significant petrochemical processing to get to this state. PAN is valued at about $5/kg in the market, which adds significant raw material cost to the manufacture of carbon fiber. A much smaller amount of carbon fiber is manufactured today from petroleum pitch. Carbon fiber from petroleum pitch has different properties when compared with its PAN counterpart. Tensile strength tends to be lower but Youngs modulus is much higher, and thermal and electrical conductivity has been shown to be superior. This opens a window of opportunities for new and innovative applications. Also, making carbon fiber from a petroleum-based starting material (referred to as a precursor) offers the potential for significant reduction in raw material costs: pitch is valued at approximately $0.30/kg, so if a petroleum-based precursor can be produced without significant additional costs, then a new market for petroleum-based residues could be more attractive than current dispositions.

Currently, the majority of petroleum residue is converted to fossil fuel products (diesel, gasoline, LPG) through processes such as coking and residue hydroconversion. This is not only true for conventional crude oils but also for oilsands bitumen. With the demand for fossil fuels in decline, and higher carbon taxes levied against the processing of oilsands and the use of its products, there is a very real threat that oilsands production could be in decline and starting as early as this decade. The implications to Alberta, Saskatchewan, and all of Canada are of concern. The oilsands economy has generated significant wealth for decades, and a future scenario where this resource becomes stranded (due to the need to decarbonize our economy) is not good news for Canadians. The answer to this dilemma lies in a strategy to "repurpose" the oil sands to make advanced materials, not fossil fuels.

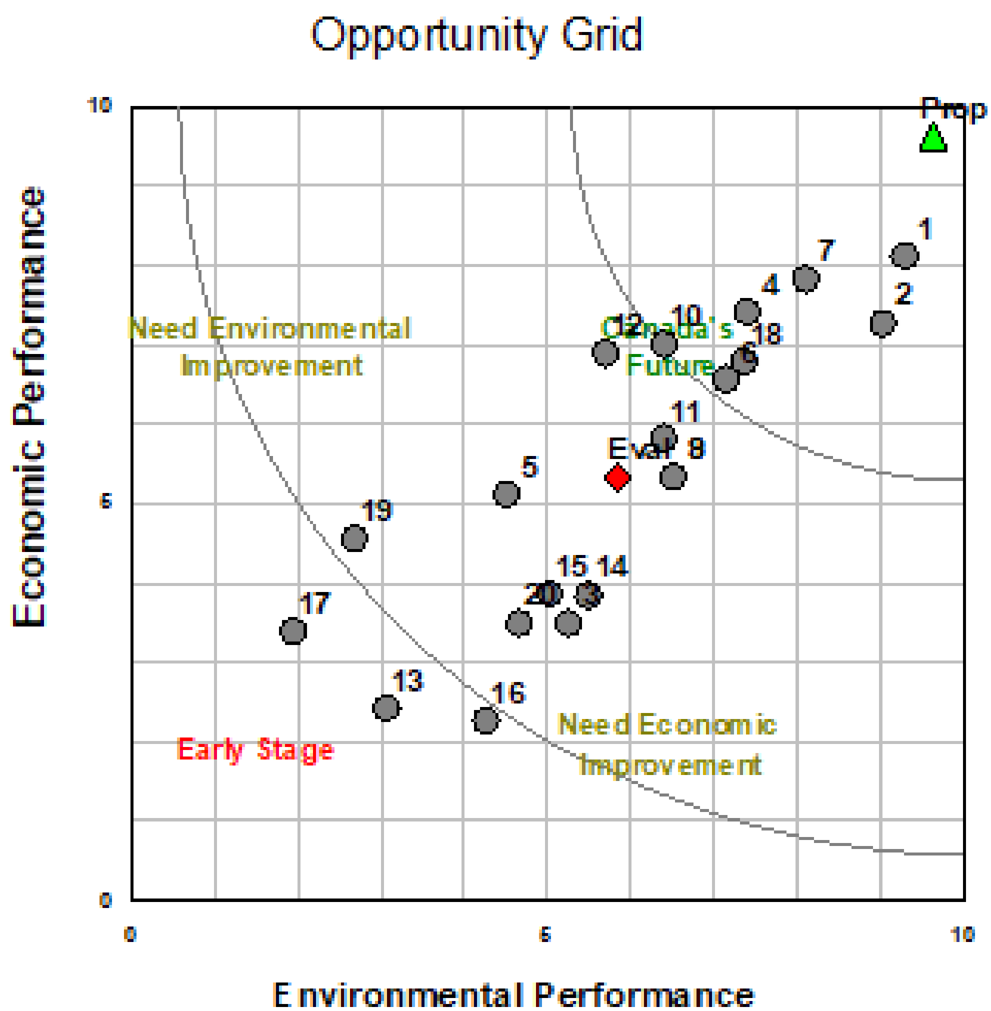
Repurposing the oilsands to make new, advanced materials such as carbon fiber requires an understanding of the processing steps, and where Canada is competitively positioned to add value to the carbon fiber value chain. There are five major steps in this chain. First, acquisition of the proper feed bitumen and processing of that feed to make high quality carbon fiber precursor material. Second, the spinning of precursor to make "green" filaments. Third, the treatment of green filaments via stabilization and carbonization to make carbon fibers; Fourth, the surface treatment of the raw carbon fibers to prepare them for their predetermined end use application, and lastly the incorporation of carbon fibers into composite forms and structures for end product use. It is easy to make a case for Canadian involvement (industry and academia) in step 1 given our history and developed know how in processing bitumen. We already understand how to characterize complex hydrocarbon molecules; how to transform them physically and chemically using thermal processes; and how to move them to markets via large scale transportation. In comparison, Canada has little to no commercial experience in spinning filaments or converting them to high-strength fibers, and would therefore find itself competitively disadvantaged from the start. Step 1 can be further detailed into the following steps. a) Atmospheric and vacuum distillation of dilbit to produce a "deep cut" vacuum residue of high softening point and viscosity; b) Pre-treatment of the residue to produce a mesophase dispersed within an isotropic continuous phase; c) Establish a growing profitable market for mesophase precursor based on production of high quality, pitch-based carbon fiber that it produces.

From a research & development perspective, there are several key milestones before the commercial production of bitumen-based mesophase precursor can occur. First, a recipe needs to be developed for an optimum composition of precursor; Second, a commercial process is required to produce this composition of precursor; Third, the capital cost and operating cost for its production is estimated to determine if there is ample margin for commercialization. This requires market research to understand the premium that can be placed on bitumen-based mesophase precursor.

The Opportunity was assessed by 20 Evaluators.

The following graph shows the evaluated Opportunity position as determined by the Proponent, each Evaluator, and the Evaluator Average, with respect to the two Overarching Objectives of Economic Performance and Environmental Performance.
The Opportunity ratings have the following characteristics:

Economic Performance = 5.3
Environmental Performance = 5.8
R Value = 56% *(The R Value is a measure of the distance of the Evaluator average grid position for the Opportunity towards to point 10,10)*



Next Steps

The next step for the Bowman Centre for Sustainable Energy is to identify, and collaborate with, proponents for each of the three evaluated opportunities.

We believe that a detailed understanding of the evaluations will guide the proponent of an opportunity to clearly state the environmental performance and economic performance of the opportunity in terms that support a sustainable energy future for Canada.

Further, the detailed understanding of the evaluations will quantify the obstacles yet to be overcome.

The result will be actionable steps for the proponent to drive Canada's energy strategy and generate economically and environmentally sustainable wealth and jobs.

Appreciation

The Bowman Centre for Sustainable Energy thanks the following Associates, and volunteers from other organizations:

Tim Bechard	Kells Boland	Dr. Clem Bowman
Ed Brost	Pierre Gingras	Dr. Murray Gray
Don Greaves	Lynne Hicks	Dr. Terry Hoffman
Dr. Anne Marie Huynh	Dr. Eddy Isaacs	Marshall Kern
John Kramers	Gary Locke	Dr. Ben Luan
Dr. Maike Lukien	Dr. Axel Meisen	Dr. Walter Petryschuk
Dr. Oskar Sigvaldason	Peter Smith	Tom Tiedje
Ashok Uppal	Guy Van Uytven	Don Wood

The Bowman Centre for Sustainable Energy acknowledges the profound influence of our founder, Dr. Clem Bowman (1930 – 2021). He was integral to the start of this multi-year effort. While he guided the teams of visionaries to develop the descriptions of the three Opportunities, he passed away before the final evaluations, and this analysis, were completed.

Appendix: ProGrid® Evaluation Matrix

<u>The ProGrid® Evaluation Matrix</u>

Nine performance criteria were used for each proposed project under three headings, Economic Performance, Canadian Readiness and Environmental Performance. Four performance levels were established for each of the nine criteria to create the Language Ladder needed to compare the three nation-building projects.

Evaluation Matrix		
Economic Performance	Canadian Readiness	Environmental Performance
National/Regional Impact	Fit to National Vision	National Env. Targets
Breadth of Impacts	Fit to Provincial Goals	Local/Regional Impacts
System Synergies	Societal Readiness	Net Societal Benefits

A short description of each of the nine criteria in the Evaluation Matrix follows:

National/Regional Impacts

This criterion seeks to evaluate the extent to which the economic impact of the project would be felt across all regions of Canada and benefit this generation as well as future generations of Canadians. The criterion covers the initial commercial application of the project and/or its expansion or replication in other regions.

Breadth of Impacts

This criterion seeks to evaluate the breadth of the economic benefit of the project across many sectors of the Canadian economy

System Synergies

This criterion seeks to evaluate the ability of the project to strengthen the economic impact of other Canadian natural resources.

Fit to National Vision

The Situation: Canadian leaders have moved opinions of Canadians to do our share in combating climate change. However, translating this support into a Canadian willingness to build big national resource projects that meet both our economic and environmental targets has yet to be achieved. New projects contributing to these targets will help define Canada's evolving national vision.

Fit to Provincial Goals

The Situation: The Council of the Federation has issued its report 'Canadian Energy Strategy, July 2015', which is intended to enable provinces and territories to move forward and collaborate on nation-building projects. However, translating this strategy into specific big projects which have broad provincial/territorial support has yet to be achieved. New projects which have the potential to secure the support of provincial and territorial leaders will continue Canada's tradition of nation building projects.

Societal Readiness

The Societal Readiness of a new Large Canadian Project is dependent on the readiness of society to accept that the project is a good project for Canada, which will result in government acceptance, as well as a consensus that the project should go ahead by the different interest groups, for example the environmental lobby, the Indigenous People whose lands will be affected and the project proponents.

National Environmental Targets

This criterion includes environmental targets that Canada has set, or accepted as part of international agreements, in the broad sense: e.g. GHG emissions, contaminant emissions to air, water and land, land use change and health concerns.

Local/Regional Impacts

This criterion evaluates the level of impact of the project at a local or regional level, assuming that its impact across Canada would not be profound.

Net Social Benefits

This criterion evaluates the broad benefits accruing to our society, including indigenous people, such as capturing the full value of our natural resources and building an environmentally-sound economy.