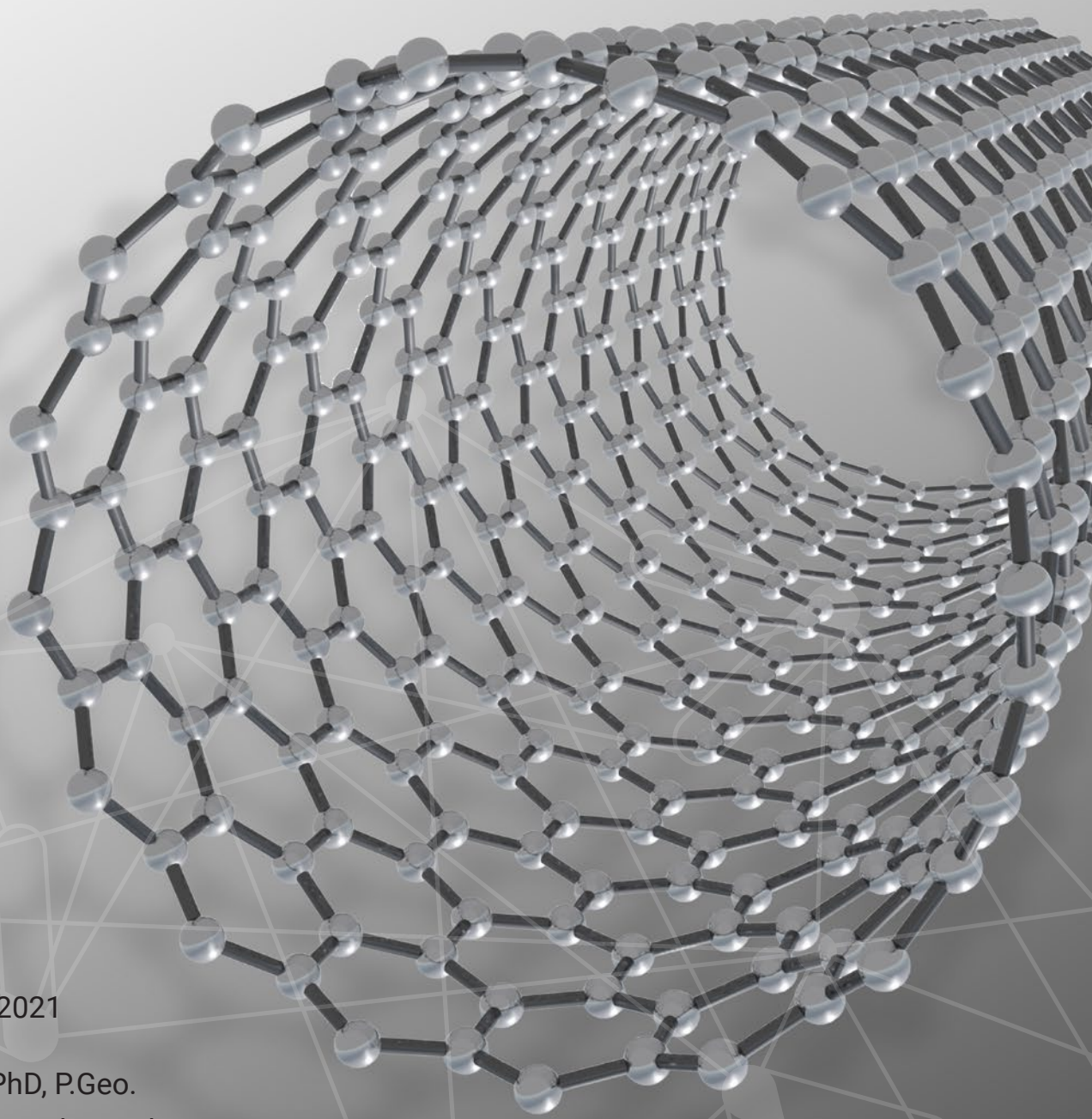
BITUMEN BEYOND COMBUSTION

HOW OIL SANDS CAN HELP THE WORLD REACH NET-ZERO EMISSIONS AND CREATE ECONOMIC OPPORTUNITIES FOR ALBERTA AND CANADA



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ALBERTA INNOVATES

About Alberta Innovates

ALBERTA INNOVATES IS THE PROVINCE'S LARGEST AND CANADA'S FIRST PROVINCIAL RESEARCH AND INNOVATION AGENCY. For a century we have worked closely with researchers, companies and entrepreneurs – trailblazers who built industries and strengthened communities. Today we are pivoting to the next frontier of opportunity in Alberta and worldwide by driving emerging technologies across sectors. We are a provincial corporation delivering seed funding, business advice, applied research and technical services, and avenues for partnership and collaboration.

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FORWARD

Alberta is poised to drive an energy evolution that can change the face of the Canadian economy and meaningfully contribute to achieving net-zero emission goals. Alberta is a globally significant centre of energy production and expertise, and a growing centre of clean tech expertise focused on transforming its key energy resources and managing them more sustainably.

We are challenged to reconcile the environmental imperative to reduce if not eliminate emissions, with the reality that oil and gas will still be in demand over the near term while the world transitions to new fuels and energy sources. However, net-zero emissions and a viable resource industry can be possible when one approaches the problem in a different way.

Alberta's natural resources, bitumen included, can contribute to the Canadian economy during the energy transition and be part of a net-zero emissions solution over the long term.

Alberta Innovates has developed a strategy to transform bitumen from oil sands, utilizing the carbon in a value chain of advanced materials and products instead of releasing it through combustion in transportation fuels. Products and materials made from bitumen can make transportation more energy efficient, infrastructure less energy intensive and more durable, and renewable generation and energy storage more economic.

In directing bitumen toward a higher value stream, emissions from processing can be sequestered through carbon capture and storage technologies. Bitumen is diverted away from fuel combustion emissions, displacing other high-GHG intensity products, and reducing downstream GHG emissions.

The opportunity for bitumen beyond combustion may not be immediately persuasive to climate activists. But this does not detract from the case we are making. Our viewpoint is based on scientific expertise, fiscal realism and deeply shared commitment to a healthy planet and low-carbon future.

We understand that trillions of dollars' worth of investment will be required to transition to a net-zero economy. We can create a multibillion-dollar clean tech engine that will propel a net-zero economy. As much as we're excited by this potential, and despite the early research Alberta Innovates has done, our "bitumen beyond combustion" strategy remains a vision. Much like the initial development of the oil sands a century ago, and SAGD technology more recently, significant investment and policy courage will be required between now and 2030 to turn this vision into reality.

By looking beyond convention, we can set in motion the next evolution of our resource industry.

Laura Kilcrease, *CEO*
Alberta Innovates

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EXECUTIVE SUMMARY*

A new vision for oil sands in a net-zero emission future

More governments and companies are making pledges to reduce greenhouse gas (GHG) emissions to net-zero emissions (NZE). NZE means the economy would either emit no GHG emissions or completely offset its emissions. It would require a total transformation of the energy systems that underpin our economies.

Globally, fossil fuels still supply 84 per cent of energy demand and account for about 75 per cent of global GHG emissions today. Net-zero emissions therefore implies a significant decline in the use of fossil fuels. In the International Energy Agency (IEA)'s net-zero scenario, fossil fuels will fall to about 20 per cent of total energy sources by 2050, and oil demand will decline by almost 75 per cent between 2020 and 2050. Fossil fuels that remain in IEA's net-zero emissions 2050 scenario are used in goods where the carbon is sequestered in products such as plastics, in facilities fitted with carbon capture, utilization and storage (CCUS), and in sectors where low-emissions technology options are scarce.

The Government of Canada has committed to reaching net-zero emissions by 2050. Canada's strengthened climate plan, *A Healthy Environment and A Healthy Economy (HEHE)*, and the 2021 federal budget commits $17.6 billion to decarbonize the economy. The plan provides strategies around energy efficiency, hydrogen and biofuels production, battery materials development, electrification in transportation, and CCUS. However, it does not provide a vision for the oil sands industry in a net-zero world.

Alberta was the first jurisdiction in North America to put a price on industrial carbon emissions. Currently, the *Technology Innovation and Emissions Reduction (TIER) Regulation* is a key tool to regulate industrial GHG emissions in Alberta. Although TIER applies to a fraction of industrial GHG emissions, the Government of Alberta has used the TIER compliance fund effectively to support innovations in emission reduction. The government has also developed a *Natural Gas Vision and Strategy* and is developing CCUS, hydrogen and other emission reduction strategies.

Recently, five oil sands producers who represent 90 per cent of total bitumen production have committed to the goal of achieving net-zero emissions by 2050. Their *Oil Sands Pathways to Net Zero* initiative is a significant commitment and will materially reduce GHG emissions in Canada, but it only focuses on emissions from bitumen production. Approximately 80 per cent of total emissions occur at the point of combustion when fuels are consumed. The greatest challenge for any fossil fuel in a net-zero emissions scenario, oil sands included, is to reduce GHG emissions related to combustion.

For Canada's net-zero commitment and economic future, it is important to address the future of the oil sands. This discussion paper seeks to address this question:

> *How can the oil sands help the world reach net-zero emissions and create economic opportunities for Alberta and Canada?*

**Dollar amounts in this paper are in Canadian currency unless indicated otherwise.*

We believe that oil sands can contribute to achieving net-zero goals if this resource is used to create products that are valued in that world. Our Bitumen Beyond Combustion (BBC) strategy provides a vision for oil sands to thrive in a net-zero economy and a pathway to get there. The BBC strategy calls for a greater portion of bitumen production to be diverted away from fuel production and dedicated to the manufacture of high-value products and materials. In doing so, the carbon from the bitumen remains sequestered within the products and not released. In fact, the carbon becomes an asset.

BBC products can make transportation more energy efficient, infrastructure less energy-intensive and long-lasting, and renewable electricity generation and energy storage more economic. Instead of contributing to the emissions problem, bitumen can contribute to energy efficiency solutions. With the industry's *Oil Sands Pathways to Net Zero* initiative as a strong foundation, BBC has the potential to create significant economic opportunities, including the creation of thousands of jobs, for Alberta and Canada while helping Canada realize its net-zero ambition.

Bitumen for non-combustion and high-value products

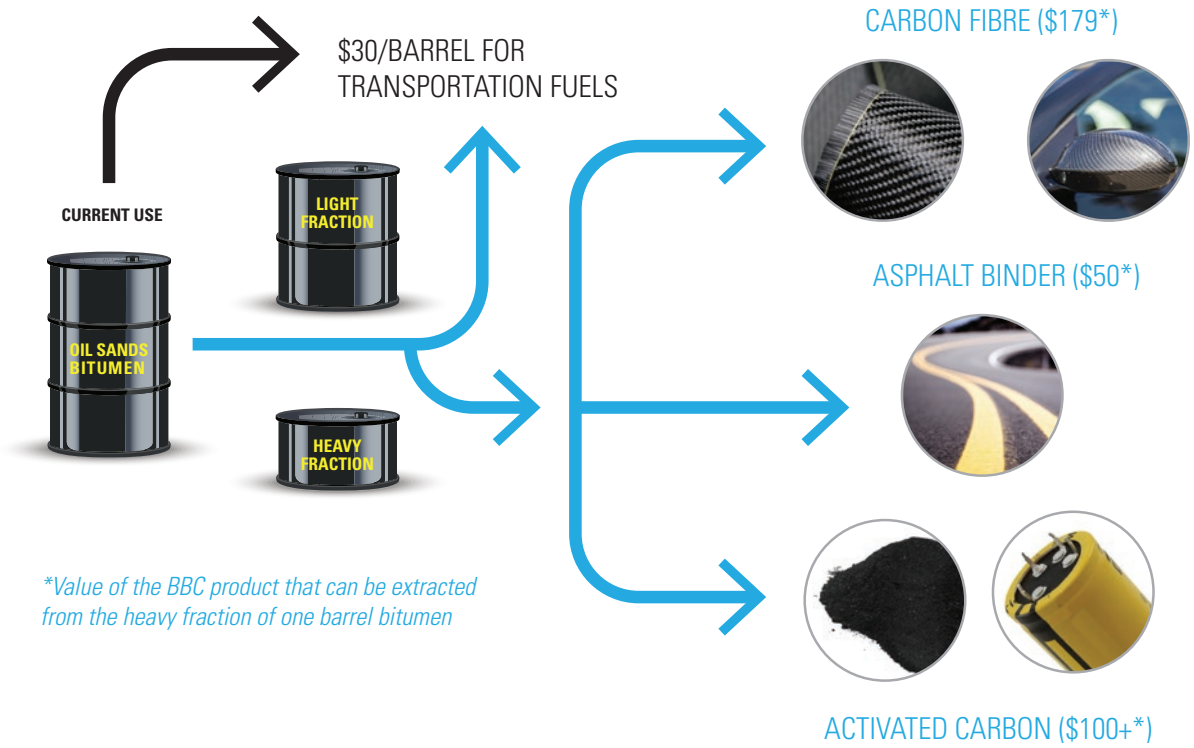
Bitumen is a sticky, viscous form of petroleum trapped in sand found in northern Alberta. It is processed to produce transportation fuels and other petroleum products. When used as a source for transportation fuels, bitumen has a lower value than conventional crudes.

The central concept of BBC is that the heavy fraction in bitumen will be diverted from fuels production and instead be used to generate materials and products with growing demand around the world. Since conception of the BBC program in 2016, Alberta Innovates has been working to assess market opportunities and develop new products and technologies. Some key BBC products include carbon fibre, asphalt binder, and high-value carbon materials such as activated carbon, graphene, carbon nanotubes, metal carbides and synthetic graphene. Market demand for these products has been growing and will continue to grow in a net-zero emissions future. For example, the Chinese carbon fibre market has been growing at a CAGR of 19.3 per cent.

If the heavy fraction is used to make carbon fibre, it can add an estimated $179 to that barrel of bitumen. At the same time, the light fraction becomes more valuable as it can be shipped and refined more easily. The total value of the bitumen barrel increases from $30 to $213. Further value addition can be realized when bitumen-derived carbon fibre is used to manufacture goods such as automobile parts.

Bitumen-derived asphalt binder has premium quality compared to other sources. When the heavy fraction of the barrel is used to make asphalt binder, the added value is $50. For high-value carbon materials, the added value could be more than $100 per barrel.

THE CENTRAL CONCEPT OF BBC IS THAT THE HEAVY FRACTION IN BITUMEN WILL BE DIVERTED FROM FUELS PRODUCTION AND INSTEAD BE USED TO GENERATE MATERIALS AND PRODUCTS WITH GROWING DEMAND AROUND THE WORLD.



Exporting one million barrels per day of bitumen will generate $11 billion per year in gross revenue for industry, based on an assumed price of $30 per barrel. If the same volume of bitumen is used to generate BBC products in Alberta, the potential revenue rises to $33 billion per year: $25 billion from BBC products and $8 billion from sales of light fraction of the bitumen. The markets for BBC products are large and growing. The actual amount of bitumen converted to BBC products and high-value carbon materials in the future will depend on successfully developing new production technologies and demonstrating the value of BBC products and materials. Significant additional economic benefit and thousands of new jobs could be realized as a result.

	Bitumen (bbl/d)	Sales Price (CAD)	Total Revenue (Annual, CAD)
Bitumen sold as crude for fuels	**1,000,000**	**$30/bbl**	**$11B**
Bitumen used for BBC products	**1,000,000**		**$33B**
Heavy fraction for BBC	470,000	$146/bbl	$25B
Light fraction for fuels	530,000	$40/bbl	$8B

BBC for GHG emissions reduction is equally compelling. Emissions reduction can be achieved in three ways: diverting bitumen away from combustion, replacing higher-intensity products, and reducing downstream GHG emissions when BBC products are in use.

- For every million barrels of bitumen used for BBC, 470,000 barrels could be diverted for non-combustion products. The emissions avoided from combustion would be 65 million tonnes per year. Since bitumen is exported for fuels to be used in other countries, combustion-related emissions would follow the consumer. As a result, not all of the 65 million tonnes of GHG emission reduction would occur in Canada.

EMISSIONS REDUCTION CAN BE ACHIEVED IN THREE WAYS: DIVERTING BITUMEN AWAY FROM COMBUSTION, REPLACING HIGHER-INTENSITY PRODUCTS, AND REDUCING DOWNSTREAM GHG EMISSIONS WHEN BBC PRODUCTS ARE IN USE.

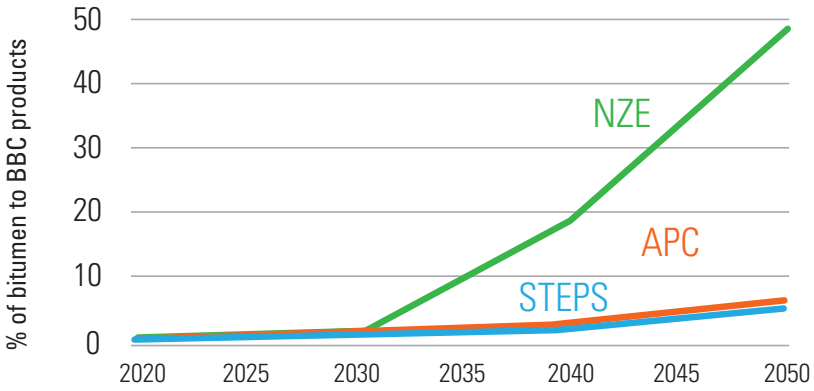
- Bitumen-derived BBC products can replace existing products with high-emission intensities. For example, life-cycle analysis indicates that the GHG intensity of bitumen-derived carbon fibre may be 52 per cent lower than that of existing commercial polyacrylonitrile (PAN) carbon fibre (Kumar et al., 2021). Similarly, improved technology could reduce GHG intensity for asphalt production by up to 30 per cent on a per barrel basis.
- The greatest climate benefit from BBC products may come in application. Carbon fibre composites in lightweight vehicles increase fuel efficiency and reduce GHG emissions by 22 to 36 per cent on a life-cycle basis as compared to a conventional vehicle (Kumar et al., 2021). Similar benefits can be found when carbon fibre is used for rail cars, shipping containers and airplanes. Carbon fibre in composite wind turbine blades enables the generation of ultra-low GHG emissions electricity. The use of carbon fibre in concrete infrastructure adds durability, longevity and reduces cracking compared to existing construction methods. Activated carbon for rapid energy storage enables more efficient use of renewable energy by complementing battery technologies. Using premium asphalt binder derived from Alberta bitumen increases the longevity of road surfaces, requiring less reconstruction and the associated emissions. The opportunity is boundless.

BBC has the potential to help the world reach net-zero emissions goals and create economic opportunities for Alberta and Canada at the same time. Innovative technologies can be developed to make highly competitive products that are and will be in high demand in a net-zero future.

Bitumen Beyond Combustion in three IEA scenarios for 2050

BBC can fit with all energy transition scenarios but provides the greatest value in a net-zero emissions scenario. This can be illustrated using three scenarios in IEA's recent report: *Stated Policies Scenario (STEPS)*, which takes account only of specific policies that are in place or have been announced by governments; *Announced Pledges Case (APC)* which assumes all announced national net-zero pledges are achieved in full and on time; and *Net-Zero Emissions Scenario (NZE)* by 2050. The potential contribution of BBC products to consumption of bitumen over time in the three scenarios is illustrated in the figure on p.9. Regardless of the scenario, the production of carbon fibres, asphalt, and high-value carbon materials can contribute $3 billion of revenue in 2030 by converting only one per cent of bitumen production.

In the STEPS and APC scenarios, the total amount of bitumen that will go to BBC products beyond 2030 will still be small. Even at these levels of conversion, these BBC products can add almost $15 billion to Alberta's and Canada's economy by 2050. In the NZE scenario, the conversion of bitumen to BBC products becomes more and more attractive as the demand for combustion fuels from crude oil sources diminishes and demand for BBC products increases.



In all the above scenarios, BBC creates more economic value and reduces climate impacts from the heavy fraction of bitumen. In the NZE and APC scenarios, the revenue from BBC after 2030 provides the incentive to significantly expand BBC capacity over time. The successful expansion of BBC production will support sustained demand for bitumen. As demand for fuels is more and more challenged after 2030, the availability of cheap light fractions of bitumen as byproducts of BBC will encourage innovation and investment in their conversion to non-combustion products.

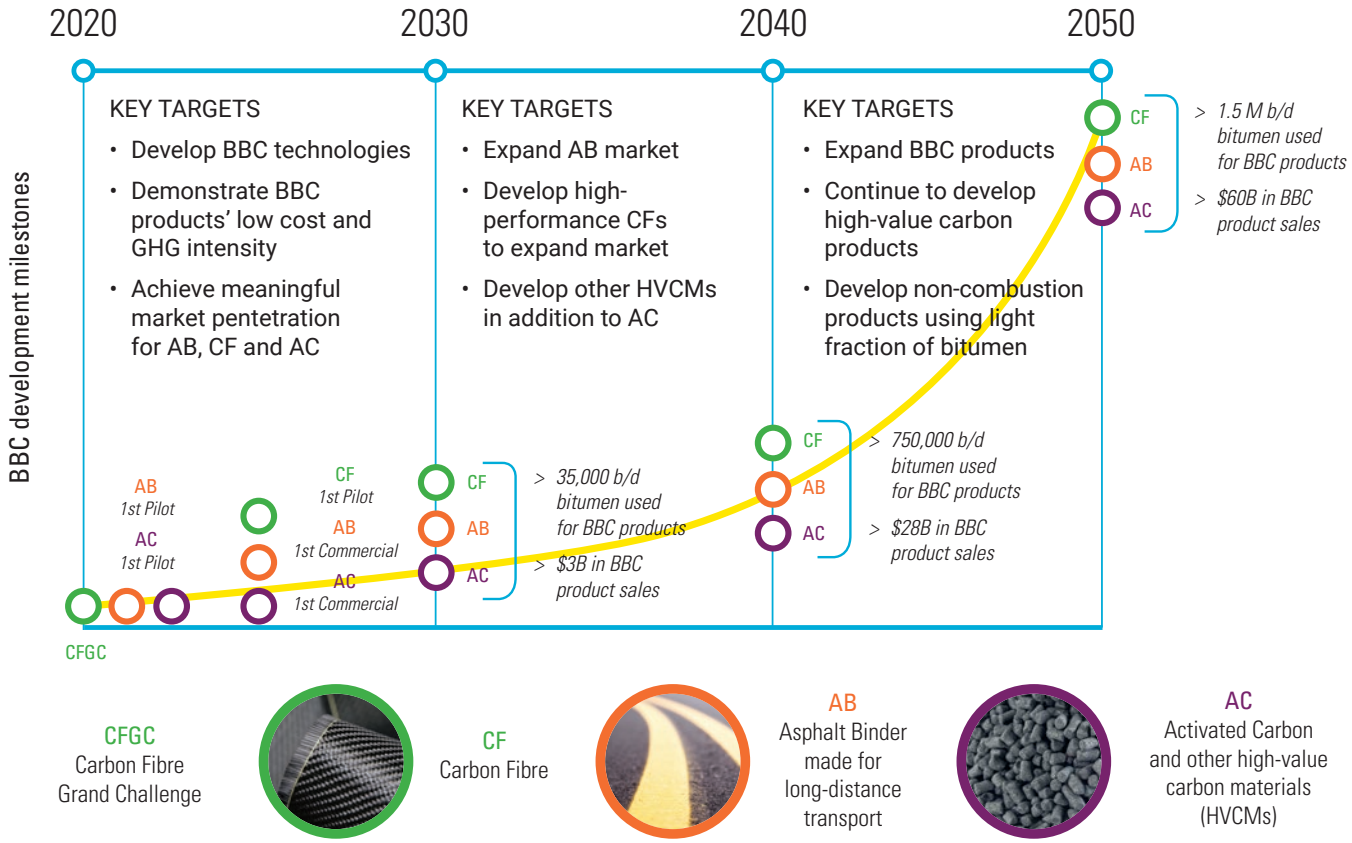
A call for leadership and investment in the future

BBC is a unique opportunity to unite economic interests with climate benefits for the common good. Achieving the greatest economic potential and climate benefits BBC can offer will require leadership and strategic investments. Through Alberta Innovates, the Government of Alberta has taken leadership in BBC development. However, BBC should be a national program because its economic impact and climate benefits will reach beyond Alberta's boundary and into whole country. The federal government should create a BBC program and invest in BBC in three phases:

1. BETWEEN NOW AND 2030, focus on development and commercialization of carbon fibre, asphalt binder and high-value carbon material technologies, and support the market use of these BBC products. More than 35,000 barrels of heavy fraction bitumen per day are diverted for BBC and to generate a $3-billion industry by 2030.

2. BETWEEN 2030 AND 2040, the focus is on expanding the asphalt binder market, developing high-performance carbon fibres to expand the market, and developing other high-value carbon materials. More than 750,000 barrels of heavy fraction bitumen per day are diverted for BBC and to generate a $28-billion industry by 2040.

3. BETWEEN 2040 AND 2050, the governments of Canada and Alberta invest in technologies for non-combustion or emission-neutral use of light fraction bitumen. The goal is that 100 per cent of bitumen will reach net zero from production to consumption by 2050. More than 1,500,000 barrels heavy fraction bitumen per day are diverted for BBC and a $60- billion industry is generated by 2050. If non-combustion products can be developed to fully utilize light fraction and heavy fraction in bitumen, the BBC products could generate over $100 billion in revenue per year by 2050.



Significant investment will be required between now and 2030. Since BBC is a transformational clean growth opportunity and the BBC technologies are at a very early stage, the early investment should be made by governments. With success of BBC product development and commercialization, private investment will drive much of the technology and market development post-2030. Investment would need to ramp up from $10 million/year in 2022 to $100 million/year after 2025, with total investment of at least $600 million between 2022 and 2030.

In the 1980s, the Alberta Government took leadership in developing oil sands resources. Through significant investment in the Alberta Oil Sands Technology and Research Authority (AOSTRA), steam-assisted gravity drainage (SAGD) technology was developed which led to a multibillion-dollar domestic industry and created thousands of jobs across the country. BBC could be another transformational opportunity. If successful, BBC can create an unprecedented economic opportunity for Alberta and help Canada and even the world to reach its net-zero ambition.

1. INTRODUCTION

More governments and companies are making pledges to reduce GHG emissions to net-zero emissions. Achieving net zero means the economy would either emit no GHG emissions or completely offset its emissions. The number of countries that have pledged to achieve net zero represents approximately 70 per cent of global GHG emissions (International Energy Agency [IEA], 2021a). At the same time, more than 100 multinational corporations have signed *The Climate Pledge*, a public commitment to drastically reduce GHG emissions and achieve net zero by 2040 *(https://theclimatepledge.com)*. As well, the Glasgow Financial Alliance for Net Zero has announced that financial sector commitments to net zero now exceed USD$130 trillion. Firms across the financial spectrum – banks, insurers, pension funds, asset managers, export credit agencies, stock exchanges, credit rating agencies, index providers and audit firms – are "delivering their fair share," having committed to high ambition, science-based targets, including achieving net zero emissions by 2050 at the latest (Glasgow Financial Alliance for Net Zero, 2021).

The Government of Canada has committed to reaching net zero by 2050. The *Canadian Net-Zero Emissions Accountability Act*, which came into effect in June 2021, formalizes Canada's target to achieve net-zero emissions by 2050, and establishes a series of interim emissions reduction targets at five-year milestones toward that goal.

Achieving net zero will require a total transformation of the energy systems that underpin our economies. The International Energy Agency (IEA)'s *Net Zero by 2050: A Roadmap for Global Energy Sector* report (IEA, 2021a) sets out 400 milestones spanning all sectors and technologies – for what needs to happen, and when – to transform the global economy from one dominated by fossil fuels into one powered predominantly by renewable energy like solar and wind.

Globally, fossil fuels still supply 84 per cent of energy demand and account for about three-quarters of global GHG emissions today (IEA, 2021a). Achieving net zero will require a significant decline in the use of fossil fuels. In IEA's net-zero scenario, fossil fuels as source of energy will fall to slightly over one-fifth of total sources by 2050, and oil demand will decline by almost 75 per cent between 2020 and 2050. The trajectory of oil demand in IEA's net-zero scenario means that no exploration for new resources is required, other than fields already approved for development. The energy company BP has committed to reducing its oil production by 40 per cent by 2030 (BP, 2020). Fossil fuels that remain in IEA and BP's net-zero 2050 scenarios would be used in goods where the carbon is sequestered in the product such as plastics, in facilities fitted with carbon capture, utilization and storage (CCUS), and in sectors where low-emission technology options are scarce.

Development of the Canadian oil sands is an innovation success story. The industry has been an economic engine for Alberta and Canada for decades.

Currently, the industry produces more than three million barrels per day, and oil sands development is expected to contribute more than $1 trillion to the Canadian economy between 2019 and 2029 (Millington, 2019).

The environmental, social and governance (ESG) performance of the oil sands industry has improved over recent decades to become one of the best oil producers in the world (Dziuba et al., 2021). GHG emission intensity in oil sands production decreased by 20 per cent between 2009 and 2018 (IHS Markit, 2018) and the emissions intensity from some large oil sands assets is comparable to the average U.S. barrel of oil (Sleep et al., 2020). However, the growth of the oil sands industry has been outpacing the rate of decrease in GHG emission intensity, and so absolute GHG emissions in oil sands production have been increasing. The total GHG emissions from oil sands extraction was 83 million tonnes in 2019, representing 11 per cent of Canada's overall GHG emissions (Environment and Climate Change Canada, 2021).

Recently, five oil sands producers who represent 90 per cent of the total bitumen production, committed to the goal to achieve net-zero emissions from the companies' oil sands operations by 2050 *(https://www.oilsandspathways.ca/)*. Their *Oil Sands Pathways to Net Zero* initiative will position Canada as the supplier of choice for responsibly produced oil to meet the world's growing energy demand. By reducing direct (Scope 1) and indirect (Scope 2) GHG emissions in oil sands operations, the *Oil Sands Pathways to Net Zero* will materially reduce GHG emissions within Canada and help to meet its climate goals.

However, Scope 1 and Scope 2 emissions account for 20 per cent of total GHG emissions in the life cycle from production to consumption. Approximately eighty per cent of total emissions occur at the point of combustion (Scope 3) when oil sands are used as transportation fuels. In a net-zero world, the greatest challenge is Scope 3 GHG reduction.

For Canada's net-zero commitment and economic future, it is important to address the future of the oil sands. This discussion paper seeks to address this question:

> *How can the oil sands help the world reach net-zero emissions and create economic opportunities for Alberta and Canada?*

We understand it is not a certainty that net-zero goals can be achieved by 2050. Indeed, the IEA notes a great gap between aspirations and actions being taken to have a fighting chance of achieving net zero by 2050. The IEA's recent reports forecast continued increase in oil demand over the near term (IEA, 2021b), and the agency urged OPEC+ members to increase production to keep the world oil markets supplied (IEA, 2021c). However, this does not remove the need for Canada and Alberta to be prepared and to take actions now to ensure that the oil sands can contribute to a net-zero global economy. It is an environmental imperative and an economic imperative.

The current climate policy approach of the Government of Canada is unlikely to secure the oil sands' future in a net-zero global economy. Canada's strengthened 2020 climate plan, *A Healthy Environment and a Healthy Economy (HEHE)* (Environment and Climate Change Canada, 2020), and the 2021 federal budget commit $17.6 billion to decarbonize our economy. It provides a strong vision and strategies in energy efficiency, hydrogen and biofuels production, battery materials development, electrification in transportation, and CCUS. However, it does not provide a vision for the oil sands industry in a net-zero world. The only strategy in the HEHE plan relevant to oil sands production is CCUS, which only addresses Scope 1 and 2 emissions. Direct air capture, which removes CO_2 from the atmosphere, cannot reach the scale needed to deal with

Scope 3 emissions from the combustion of fuels derived from the oil sands, including gasoline, diesel and jet fuel (Alberta Innovates, 2021a). Without a clear strategy and pathways for Scope 3 emission reduction, the oil sands industry will likely face significant challenges as the world marches toward net zero, and a significant opportunity for Canada to transform the oil sands into a strategic resource into the future could be missed.

Alberta was the first jurisdiction in North America to put a price on industrial carbon emissions. Currently, the *Technology Innovation and Emissions Reduction (TIER) Regulation* is Alberta's industrial GHG emissions pricing regulation and trading system. Facilities regulated under TIER must reduce emissions to meet facility benchmarks. Although TIER applies to a fraction of industrial GHG emissions, the Government of Alberta has used the TIER compliance fund effectively to support innovations in emission reduction. The government has also developed a *Natural Gas Vision and Strategy* and is developing CCUS, hydrogen and other emission reduction strategies.

Alberta Innovates proposed a vision and a strategy for Bitumen Beyond Combustion (BBC) in 2016 and since then has been working with key stakeholders (including the Bowman Centre for Sustainable Energy) to drive this initiative forward. Our BBC program directs a greater percentage of bitumen to be used for value-added products instead of combustion fuels. In application, BBC products can make transportation more energy efficient, infrastructure less energy intensive and long-lasting, and renewable generation and energy storage more economic. Instead of being used for transportation fuels and thus a source of GHG emissions, BBC oil sands products can help the world achieve net-zero emissions. With the industry's Oil Sands Pathways to Net Zero initiative as a strong foundation, BBC has the potential to create significant economic opportunities, including the creation of thousands of jobs for Alberta and Canada while helping Canada realize its net-zero ambition.

WITH THE INDUSTRY'S OIL SANDS PATHWAYS TO NET ZERO INITIATIVE AS A STRONG FOUNDATION, BBC HAS THE POTENTIAL TO CREATE SIGNIFICANT ECONOMIC OPPORTUNITIES, INCLUDING THE CREATION OF THOUSANDS OF JOBS FOR ALBERTA AND CANADA WHILE HELPING CANADA REALIZE ITS NET-ZERO AMBITION.

Global population is expected to reach 9.7 billion people by 2050, almost two billion more than in 2020 (United Nations, n.d.). A population expansion of 25 per cent will increase the need for materials to supply housing, transportation, infrastructure, consumer goods, etc. Manufacturing and processing raw material inputs (e.g., steel, cement, aluminum, etc.) is a major source of greenhouse gas emissions, accounting for 21 per cent of total global emissions (Gates, 2018).

Decarbonizing this sector remains a significant challenge and does not often receive the attention that transportation and other sectors do (Daigle, 2021). Consumers are increasingly desiring goods and/or products that are made in a sustainable manner, which will reduce environmental impacts over time. We believe that Alberta's bitumen resources are an ideal, plentiful and reliable source of feedstock required to manufacture the sustainable materials the world requires now and into the future.

This discussion paper advances a comprehensive vision for BBC and calls for leadership and action. Following this introduction, Section 2 describes the vision for BBC, the nature of BBC products, their climate and economic impacts for Alberta and Canada, and how BBC products can reduce downstream GHG emissions when deployed. Section 3 outlines how BBC can provide climate and economic benefits in any energy transition scenario, including net zero by 2050. Section 4 is a call for leadership and investment in BBC. Similar to many transformational technologies such as the Internet, GPS, artificial intelligence and Alberta's own steam-assisted gravity drainage (SAGD) for oil sands extraction, BBC will require government leadership and investment to turn the vision into a reality.

2. BITUMEN BEYOND COMBUSTION (BBC)

Bitumen is the heaviest grade of crude oil, present in the Alberta oil sands as a mixture with sand, clay and water (Canadian Association of Petroleum Producers [CAPP], n.d.). Once separated, bitumen is treated for delivery to refineries where conversion to fuels and non-combustion products occurs. The bulk of the bitumen is used for transportation fuels and a small fraction is used for asphalt. Bitumen comprises light and heavy fractions and is rich in the latter compared to conventional crude oils. The heavy fraction that can be used for non-combustion products ranges from 15 to 50 per cent of a barrel of bitumen, depending on end use. If sent to a refinery, the heavy fraction of bitumen requires more processing than conventional crude oils to produce gasoline and other petroleum products.

The BBC program directs the heavy fraction of bitumen to be diverted away from fuel production and dedicated to the manufacture of high-value materials. In doing so, the carbon from the bitumen remains trapped or sequestered within the products and not released.

BBC is intended to:

- diversify the uses of Alberta's oil sands bitumen, resulting in high-value, large-scale, non-combustion products that can be marketed globally, thereby creating a new value-add industry;
- reduce greenhouse gas emissions associated with the utilization of bitumen; and
- contribute to reducing global greenhouse gas emissions by creating lower GHG intensity, lightweight products to displace more GHG-intensive metal and glass products used in various industrial sectors including transportation and infrastructure.

The program targets large-volume, non-combustion products and their associated production technologies which:

- are technically and commercially feasible;
- are competitive with, or superior to, existing products and production technologies;
- have lower GHG intensities compared with existing products and production technologies;

- will collectively require use of at least 100,000 barrels of bitumen per day (bpd) by 2030; and
- contribute to a diversified economy in an environmentally responsible and sustainable manner.

We commissioned two seminal whitepapers in 2017 (Meisen, 2017) and 2018 (Stantec Consulting, 2018) that broadly defined the technical and economic opportunities related to BBC. Top BBC products identified by the white papers include carbon fibre, asphalt binder and high-value carbon materials (e.g., activated carbon, graphene, carbon nanotubes, metal carbides and synthetic graphene). These are attractive BBC products because they sequester carbon from bitumen, as opposed to bitumen being converted to fuels and combusted.

Bitumen is ideally suited as a feedstock for non-combustion products

The heavy fraction of bitumen is highly viscous (does not flow easily) and contains metals and sulfur which drive down the value. However, the heavy fraction possesses chemical and physical properties, relative to other global crude oils, beneficial for the manufacture of products such as carbon fibre, asphalt binder and high-value carbon materials:

- The dominant carbon fibre manufacturing process begins with crude oil but requires multiple steps and chemical conversions (and associated energy/GHGs) to produce propylene, ammonia, acrylonitrile and finally polyacrylonitrile – the starting material for 90 per cent of today's global carbon fibre manufacturing. Fibres spun from polyacrylonitrile are heat-treated at temperatures higher than 1,200 to 1,500°C to form carbon fibre (Zoltek, n.d.). On the other hand, using the heavy fraction of bitumen as a starting input feed would require less chemical conversion and energy/GHGs to generate the necessary starting material for carbon fibre, while subsequent heating steps would require similar or less energy input. The heavy fraction of bitumen also has significant potential advantages on yield and scaling via melt-spinning. Overall, carbon fibre derived from bitumen has a lower embedded GHG intensity than other carbon fibre currently being made. There is also a very significant cost advantage, as the feedstock now being used costs $10/kg (constituting almost 50 per cent of the total cost of carbon fibre), while the heavy fraction of bitumen costs less than $1/kg. Studies have shown that cutting the total cost of carbon fibre in half will lead to a potential 10-fold market growth (Warren, 2011) from the current 100,000 tonnes/year. As an indication, the Chinese carbon fibre market has been growing at a CAGR of 19.3 per cent and its projected market by 2025 will be 150,000 tonnes (greater than the total global market today), with 55 per cent produced in China (CICC 中金公司, 2021).
- The heavy fraction of bitumen has a naturally lower wax content than other crude oils. Because of this, asphalt binder (the "glue" that holds the different components of asphalt pavement together) derived from bitumen has high durability and resistance to cracking, placing its properties among the best in the world when compared to other asphalt binders from global crudes. (Hesp, 2021).
- High-value carbon materials are structured with rings of carbon atoms. Bitumen's heavy fraction naturally contains a high concentration of molecules containing carbon rings, making it an abundant feed source for use in manufacturing these materials. For example, activated carbon,

derived from raw materials such as biomass and coal, is produced in many different grades for diverse applications. Neither biomass nor coal give the properties required for energy storage – a very high surface area and high purity. However, this high grade of activated carbon can be produced from the heavy fraction of bitumen.

Progress in BBC program to date

Alberta Innovates realized the opportunity that the natural properties of bitumen offered for generating non-combustion products and began supporting research to exploit them. Since 2017, 27 BBC research and development projects focused on converting the heavy fraction of bitumen to carbon fibre, asphalt binder and high-value carbon materials have been funded and completed. Key research areas and learnings are presented below in Table 2.1.

Table 2.1

Progress in BBC

BBC Product	Carbon Fibre	Asphalt Binder	High-Value Carbon Materials (HVCMs)
Development Target	• Develop low-cost, low-emission bitumen-carbon fibre (B-CF) technology and manufacturing process • Life-cycle analysis of GHG emission B-CF pathway • Market development of B-CF	• Benchmark new bitumen derived asphalt binders (B-AB) against commercial asphalt binders • Development of higher performing and durable B-AB for road base layers • New methods for transporting B-AB shipment at ambient temperatures	• Convert the heavy fraction of bitumen to HVCMs including activated carbon • Life-cycle analysis of GHG emission for HVCM products • Market development of HVCMs
Progress to Date	• A global carbon fibre manufacturer has been engaged and has been providing advice • Collaborations have been developed with two leading carbon fibre labs in the world • Carbon Fibre Grand Challenge (CFGC) Phase I has been successfully completed • Two pre-treatment technologies for B-CF have been developed • A dozen of B-CF technologies are being advanced in CFGC Phase II • Preliminary LCA study confirmed B-CF's GHG benefits	• A market study performed and confirmed market potential for B-AB in North America and Asia • Lab study confirmed B-AB's performance superiority over commercial asphalts from around the world • A 1,000 b/d B-AB demonstration is underway • A FEED study is being conducted for a new 6,600 b/d B-AB	• A market study is underway for bitumen-derived activated carbon • Activated carbon with a high surface area has been developed using heavy fraction of bitumen and a demonstration plant is under construction • A process has been developed to convert heavy fraction of bitumen to graphene
Remaining Challenges	• B-CF technology development still at early stage • Scaleup has not yet started • More detailed economic analysis to be done • Better LCA analysis on GHG emission • End-use product testing • Market development	• More B-AB technologies to be developed and demonstrated • Methods for transporting B-AB at ambient temperatures to be developed and demonstrated • Field-scale testing of B-AB products • Economic analysis to be done • Better LCA analysis on GHG emission • Market development	• HVCM technology development still at early stage • Except for activated carbon, scaleup has not yet started • Economic analysis to be done • Better LCA analysis on GHG emission • End-use product testing • Market development

Encouraging progress is being made in advancing carbon fibre manufacturing technology, asphalt binder performance awareness, and manufacture of high-value carbon materials. While progress is promising, development is at a very early stage for carbon fibre and high-value materials. An additional 25 BBC projects are ongoing, building on the learnings to date. This includes support for 12 projects in Phase II of the Carbon Fibre Grand Challenge, a demonstration facility for producing activated carbon (300 tonnes/year), and a pilot facility to produce asphalt binder (1,000 bbl/day) that can be transported at ambient temperatures. Alberta Innovates will continue to seek and support BBC projects of the highest quality.

Adding value through BBC

Most of the bitumen or bitumen-derived fuels produced today in Alberta are exported. Economics for building new fuel refineries in Alberta are a challenge. Thus, for the following illustration, the status quo is the shipment of bitumen (either processed or not) out of Alberta. The market price assumed for the purchase of bitumen or processed feed is $30/bbl. While this price is conservative, it represents a future case where demand declines compared to present day.

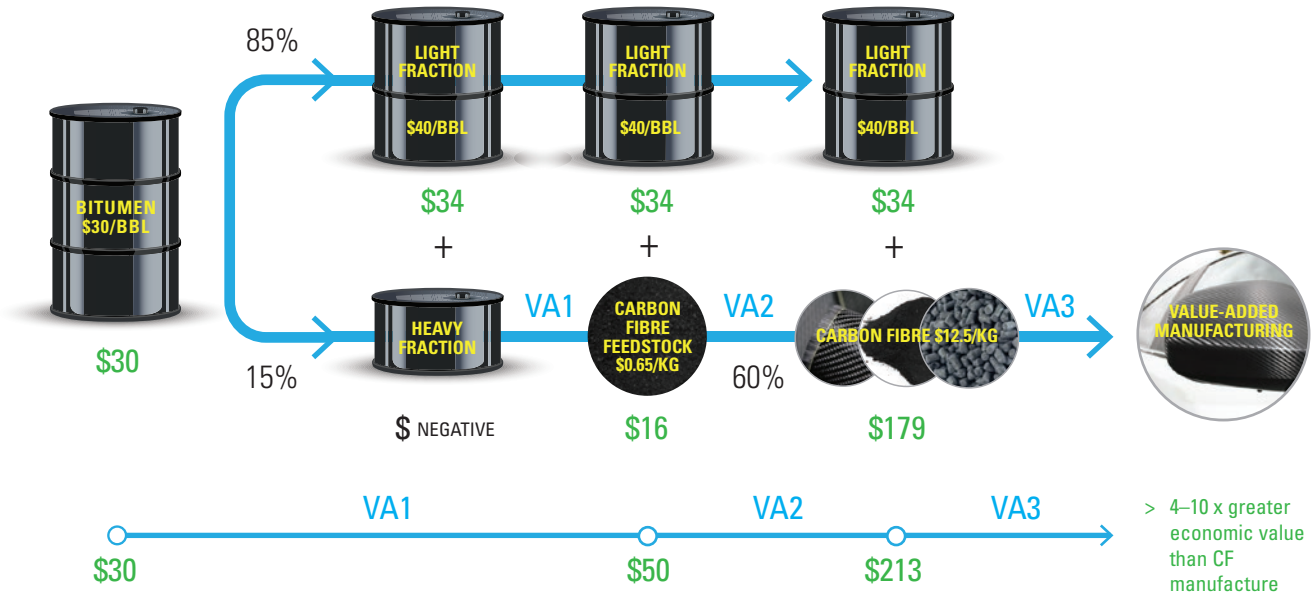
BBC products generated in the following illustration are assumed to have their entire value chain of manufacture in Alberta, and that all economic benefits arising from manufacturing remain in Alberta. While it is unrealistic to assume that every unit of BBC product will be manufactured in Alberta, given manufacturing capabilities elsewhere, it is reasonable to believe that Alberta companies can capture a market share for manufacturing BBC products.

Gross revenues are used in the following illustration to demonstrate the economic opportunity as it is too early to characterize the manufacturing costs. While this prevents calculations of net present value and return on investment, it provides a scale of economic potential. We will use information gathered from sponsored research projects over the next year to create more detailed economic models. This illustration assumes that the manufacture of carbon fibre from the heavy fraction of bitumen is economical.

A breakdown of the revenue generated from a barrel of bitumen when it is transformed into carbon fibre and associated composite products is illustrated in Figure 1 on the next page. Carbon fibre generation begins from a barrel of bitumen sold at a market price of $30/bbl. The heavy fraction must be separated from the rest of the bitumen barrel. Roughly 15 per cent of the original barrel is the heavy fraction. The remaining 85 per cent is now a light fraction that would sell for a market price of $40/bbl. The light fraction of bitumen would generate $34/bbl in revenue. Additional processing of the light fraction of bitumen would occur outside Alberta, as is the status quo.

Figure 1

Illustrative revenue increase on a per barrel basis for bitumen used for carbon fibre and associated composites *(All values in Canadian dollars)*



Carbon fibre feedstock, created from the heavy fraction, is assigned the price of asphalt binder ($0.65/kg), generating $16 in revenue from its sale to carbon fibre manufacturers (VA1). Carbon fibre generated from the carbon fibre feedstock would sell for $12.5 per kg (the target price defined in the 2021 Alberta Innovates Carbon Fibre Grand Challenge), generating $179 in revenue. Combined with the $34 revenue from the light fraction of bitumen, the total revenue is now $213 (VA2). In this illustration, sales of carbon fibre would be to customers outside Alberta. This represents a seven-times increase in revenue per barrel, within Alberta.

Carbon fibre is a material that is added to plastics, wood and other materials to create composite manufactured products that end users need. Based on current market values, this step is estimated to be worth multiples of the value of carbon fibre manufacture. With strong manufacturing hubs in Quebec and Ontario, as well as emerging manufacturing in Alberta and other provinces, the opportunity is here for Canada to increase the manufacture of products that incorporate carbon fibre. Carbon fibre production and the associated manufacturing is truly a pan-Canadian economic opportunity and one that could create jobs and provide economic benefits for decades to come.

Alberta companies can diversify their customer base for bitumen, unlock new value chains and increase revenue streams by pursuing BBC pathways. Using bitumen for the manufacture of carbon products instead of fuel can increase the revenue generated from this natural resource.

USING BITUMEN FOR THE MANUFACTURE OF CARBON PRODUCTS INSTEAD OF FUEL CAN INCREASE THE REVENUE GENERATED FROM THIS NATURAL RESOURCE.

Economic potential of BBC for Alberta and Canada

Using the same assumptions as in the previous section, increasing the amount of non-combustion products derived from bitumen offers a compelling increase in economic potential. Table 2.2 below illustrates the revenue increase by diverting one million barrels a day to manufacturing BBC products instead of selling the bitumen to refineries at market price. BBC products would be sold as export products with revenues retained in Alberta. If one million barrels per day of bitumen is exported from Alberta and sold to refineries at $30/bbl (after diluent removal), the revenue is $11 billion. Comparatively, if the same volume of bitumen is used to generate BBC products in Alberta, the potential revenue rises to $33 billion: $25 billion from BBC products and $8 billion from sales of the light fraction of bitumen.

In addition, the light fraction of bitumen would compete strongly against low-cost competitors in an over-supplied oil market and could be viewed as lower-emission intensity supply, since the balance of the barrel is going to non-combustion products. These scenarios assume the complete value chain for manufacturing non-combustion products occurs inside Alberta and Canada and is not outsourced to foreign jurisdictions. This is done for illustrative purposes to highlight the scale of the opportunity, and it is reasonable to assume that manufacturing of BBC products will also occur outside of Canada. The actual amount of bitumen that is converted to BBC products in the future will depend on successfully developing new production technologies and demonstrating the value of BBC products. Therefore, significant new economic benefit and thousands of new jobs can be realized as compared to current practice.

Table 2.2

Revenue increase with and without BBC products for one million barrels per day bitumen production (illustrative)

	Bitumen (bbl/d)	Sales Price (CAD)	Total Revenue (Annual, CAD)
Bitumen sold as crude for fuels	**1,000,000**	**$30/bbl**	**$11B**
Bitumen used for BBC products	**1,000,000**		**$33B**
Heavy fraction for BBC	470,000	$146/bbl	$25B
Light fraction for fuels	530,000	$40/bbl	$8B

Current market demand for each BBC product is very different. Approximately 140 million tonnes/year of asphalt binder is consumed globally, compared to 100,000 tonnes/year of carbon fibre. In contrast, new products made from high-value carbon materials (activated carbon, graphene, carbon nanotubes, metal carbides, synthetic graphene) are in very early stages of commercialization with production below 10,000 tonnes/year.

Table 2.3 (p. 20) provides an estimate of the proportion of BBC products with revenue potential based on market projections for each product. The amount of suitable heavy fraction of bitumen able to be converted to BBC products is based on the properties of the heavy fraction, and corresponding processes to manufacture each BBC product depends on the chemistry of the product and the conversion process. Less than half of the heavy fraction of bitumen is suitable for making carbon fibre and high-value carbon materials, while nearly all the heavy fraction is used for asphalt binder. In this product slate, asphalt

binder will be the largest BBC product by mass and has the greatest revenue potential. Realizing this potential requires the development of new technologies for transporting asphalt as solid pellets, rather than a molten liquid. Carbon fibre sold at $12.50 per kg would be the most competitively priced carbon fibre in the world and would generate $7 billion in revenue. High-value carbon materials would require less carbon per unit than asphalt or carbon fibre. Thus, the amount produced annually is smaller, along with their revenue potential.

Table 2.3

Proportion of BBC products from one million barrels per day of bitumen

	Carbon Fibre	HVCMs	Asphalt Binder	Total
Bitumen feed (bbl/d)	100,000	10,000	890,000	1,000,000
Percentage of heavy fraction required for BBC products	Less than half	Less than half	Nearly all	
BBC products (t/y)	580,350	58,035	25,825,575	
BBC revenue potential (CAD)	$7B	$1B	$17B	$25B

While the scenario described above offers a specific example of the production of different BBC products, a range of production of each product is possible, still resulting in significant revenue potential. In this scenario, the remaining fraction of the bitumen barrel that is not used for BBC products is the light fraction.

Table 2.2 above does not capture the potential economic benefit from any downstream manufacturing in Canada of value-added consumer goods that use the BBC products as inputs. The manufacturing value chain of BBC-related products can employ Albertans and Canadians of all skill levels. It represents a significant job opportunity for Albertans and Canadians with oil and gas sector experience, as well as those in chemical, manufacturing and construction industries.

Potential of BBC to reduce GHGs

BBC can reduce GHG emissions in three ways: diverting bitumen away from combustion, displacing high-intensity products, and reducing downstream GHG emissions when BBC products are in use.

Diverting bitumen away from combustion

By diverting some bitumen away from combustion, BBC is one of few pathways to reduce Scope 3 emissions (emissions from combustion as transportation fuel). For every million barrels of bitumen used for BBC, 470,000 barrels will be for non-combustion products (Table 2.2). Associated Scope 3 emission reductions would be 65 million tonnes per year (470,000 bbl/d x 365 d/yr x 0.4 tonne/bbl). It should be noted that Scope 3 emissions occur on the consumption side and that not all the GHG emission reduction will occur in Canada. Some may even argue that a barrel of bitumen taken out of combustion will be replaced by another barrel of oil from another jurisdiction as long as demand is there. However, in a net-zero scenario, when consumption of combustion fuels become highly restricted, BBC can still enable bitumen production and consumption as non-combustion products.

In addition, the economic potential in BBC will provide an extra incentive for the oil sands industry to accelerate the decarbonization of oil sands production. Reduction of Scope 1 and 2 emissions then becomes an investment for the future. In turn, the technologies (e.g., CCUS) developed in reducing Scope 1 and 2 emissions will also help decarbonize BBC manufacturing processes.

BBC products displace higher GHG intensity products

BBC products can be manufactured in a way that takes advantage of the natural properties of the heavy fraction of bitumen, resulting in similar or reduced GHG intensity compared to current products. Table 2.4 describes how the three major BBC products compare on an intensity basis with their incumbent counterparts.

Table 2.4

Comparison of GHG emission intensities of BBC products with current products

Product	GHG Emission Intensity Comparison
Carbon Fibre	A recent study indicates that the life cycle GHG intensity of bitumen-derived CF may be 52 per cent lower than carbon fibre derived from polyacrylonitrile (Kumar, 2021).
HVCM: Activated Carbon	For activated carbon for supercapacitors, bitumen is highly competitive with coker feeds in terms of yield and GHG emissions. Neither biomass nor coal-derived activated carbon is suitable for supercapacitor use.
Asphalt	Asphalt binder production is an established process within existing refineries. New refinery builds, or modification of existing refineries to incorporate improved technology, would have an equal or reduced GHG intensity for asphalt production. Reductions could potentially reach 30 per cent on a per barrel basis.

BBC products produced with lower manufacturing energy and emissions should interest consumers conscious about low-GHG products. Furthermore, GHG emissions generated in the manufacture of BBC products can be sequestered via carbon capture and storage technologies, resulting in an ultra-low GHG emissions manufacturing process.

Reducing downstream GHG emissions with BBC products

Carbon fibre, activated carbon and asphalt binder sequester carbon from bitumen, as opposed to bitumen being converted and then combusted as fuel. These products help enable reductions in downstream emissions by end users with examples found in Table 2.5 on the next page.

Table 2.5

Downstream applications of BBC products and associated emissions reduction method

Application (BBC Product)	Rationale for Downstream Emissions Reduction
Renewable Energy Production From Wind *(Carbon Fibre)*	Carbon fibre is blended with polymers to make composite wind turbine blades. Without the strength and durability of carbon fibre composites, wind turbine blades would not be as lightweight or durable and not as effective at generating ultra-low GHG emissions electricity.
Energy Storage in Supercapacitors and Batteries *(Activated Carbon)*	Activated carbon is an important ingredient in supercapacitors and batteries, enabling more efficient, low-cost manufacture and operation of these energy storage devices. These are critical components in emerging smart grids and renewable energy systems that reduce consumer electricity emissions.
Transportation – auto, rail, marine, aerospace *(Carbon Fibre)*	Carbon fibre composites in lightweight vehicles increase fuel efficiency per kilometre. On a life-cycle basis, a carbon fibre vehicle emits 22 to 36 per cent per cent fewer GHG emissions than a conventional vehicle (Kumar, 2021). For the rail industry, carbon fibre can be used to replace steel in bogies and other equipment, reducing the overall weight of rail cars and pressure applied to tracks, thereby increasing their longevity. Carbon fibre in marine applications is valued for creating more lightweight shipping containers but also for its anti-corrosion properties, increasing longevity of marine equipment. Carbon fibre in aircraft reduces weight and corresponding fuel usage, and also enables more comfortable humidity levels in the cabin, such as the Boeing 787 Dreamliner.
Sustainable Transportation Infrastructure – concrete, structural materials, roads *(Asphalt Binder, Carbon Fibre)*	Asphalt binder from Alberta ranks among the best binders in the world for durability (Hesp, 2021). Using asphalt binder derived from Alberta bitumen increases the longevity of road surfaces, requiring less reconstruction and the associated emissions. The use of carbon fibre in concrete infrastructure adds durability, longevity and reduces cracking compared to existing construction methods. The use of carbon fibre instead of steel rebar would add corrosion resistance to concrete structures, significantly extending their life and eliminating the risk of failure from corrosion. Companies have expressed interest in using carbon fibre as an additive to their concrete products, but costs are still prohibitive.
Built Environment *(Carbon Fibre)*	The use of carbon fibre increases the strength, rigidity and durability of wood panels, concrete and composite materials used in the built environment. Corrosion risk in concrete is reduced. Extending the life of the built environment will necessitate fewer repairs and reconstruction in the future, saving on emissions associated with manufacturing replacement building materials and the building process itself.

BBC summary

BBC represents a significant economic diversification opportunity to create new end uses and industries from valuable local feedstocks. It is for all these reasons that Alberta Innovates has invested significant time and energy into the BBC program and will continue to do so in the future.

BBC products can meet the global need for material goods manufactured in a sustainable manner and which are long lasting and add value to end users. These are products that the world needs today and for decades to come. BBC can increase the competitiveness and future markets for bitumen. Furthermore, these products maximize revenue derived from bitumen.

BBC pathways offer more economic and carbon reduction value from the heavier fraction of bitumen. Increasing the production of non-combustion products through BBC pathways will generate the light-fraction resources needed to explore and develop pathways to convert light fraction for non-combustion use.

Over the past five years Alberta Innovates has built a strong foundation for BBC. White papers provided early direction and guidance around the opportunity and subsequent projects demonstrated the conceptual feasibility of manufacturing non-combustions products from bitumen. Our program has generated national and international attention. We are collaborating with partners from around the world on our Carbon Fibre Grand Challenge. Concurrently, Alberta Innovates is building capacity for BBC product development in Alberta at the University of Calgary, University of Alberta and multiple small-medium enterprises. We have support from the oil sands industry in the form of heavy fractions of bitumen for testing. Bitumen producers, manufacturers and end users have been engaged and are participating in the program.

Despite the success thus far, much more work needs to be done to make the BBC vision a reality. Developing carbon fibre from bitumen is at the early stage of development; scaleup to manufacturing has yet to begin. It is very important to raise awareness in the United States about the superior quality of asphalt binder from Alberta and demonstrate this through field trials. Cheaper long-distance transport of asphalt binder at room temperature would unlock new markets. A number of high-value carbon products are in the early stage of development, more work is needed to realize their potential.

Most of this work remains too early and risky for private capital to invest, but over the next few years will reach a technology level suitable for private investment. Ensuring private investors are kept aware of BBC advancement is a pillar of the plan going forward. End-user engagement through the technology development process will be very important to ensure that BBC products will have commercial receptors once they are ready for manufacture. Governments will need to ensure policies are developed and implemented that enable BBC products to be manufactured in Alberta and Canada.

3. BITUMEN BEYOND COMBUSTION IN THREE IEA SCENARIOS FOR 2050

The transition of the world's energy supplies from a heavy reliance on fossil fuels to global GHG neutrality requires the rapid replacement of a large fraction of fossil fuel energy, transportation and industrial infrastructure. In heavy industry and agriculture, new technologies need to be developed and implemented at an unprecedented pace for peacetime and with global scope. The International Energy Agency (IEA) provides three possible scenarios for energy use to 2050 (IEA, 2021a). In every one of these scenarios, an investment in BBC creates wealth for Canada and contributes to achieving national and international climate-change targets.

BBC in Stated Policies Scenario (STEPS)

The IEA *Stated Policies Scenario (STEPS)* only include specific policies that are in place or have been announced by governments. Due to the gap between announced targets and implemented policies to drive the energy transition, global GHG emissions are projected to rise slightly to 2030 then remain stable to 2050. In this scenario, the use of renewables increases to almost 55 per cent of global electricity generation in 2050 (up from 29 per cent in 2020), but clean energy transitions lag in other sectors. Declines in transportation fuel use in OECD countries is offset by demand in developing countries and for petrochemical products, resulting in a 15 per cent net increase in global crude oil consumption from 2020 to 2050.

In Canada, refining bitumen into liquid transport fuels would be the dominant production pathway. Using the assumptions of STEPS, the production of BBC products would expand the market for oil sands bitumen and add value to the bottom of the barrel (heavy fraction), which is least valued for liquid fuels production. A small percentage of bitumen would be converted to BBC products, rising from one per cent of bitumen in 2030 to five per cent in 2050.

BBC in Announced Pledges Case (APC)

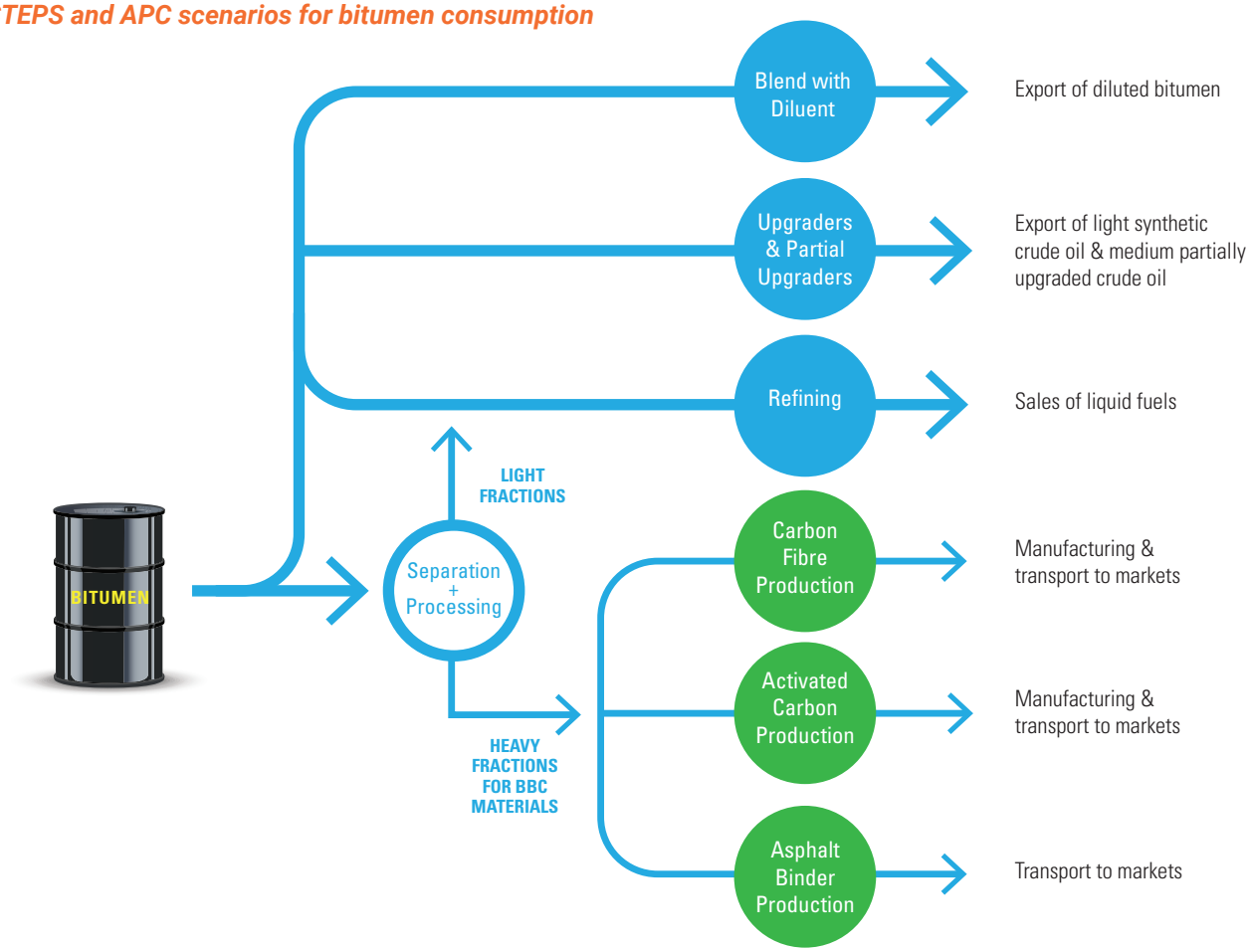
In the IEA *Announced Pledges Case (APC)* scenario, all announced national net-zero pledges are achieved in full and on time. Significant global reductions in GHG emissions are achieved by 2050, but additional measures are required between 2050 and 2100 to keep global temperature rise under 2°C. By 2050, electrical generation capacity is almost doubled, with almost 70 per cent coming from renewables. Consumption of crude oil remains significant at about 80 million barrels per day in 2050, mainly in non-OECD countries.

Using the assumptions of APC, bitumen production would continue but oil sands producers would eliminate, capture or offset GHG emissions associated

with the production and processing of crude oil and bitumen to contribute to meeting Canada's targets. Exports of crude oil and refined crude oils and refined liquid transportation fuels would continue, but the Canadian market would be transformed by electrification and the use of renewable feedstocks. BBC products would offer strong returns on investment for processing of bitumen for both non-combustion products and light fraction crude oil for export. This combined market for bitumen is illustrated in Figure 2 below. The percentage of bitumen converted to BBC products would increase from one per cent in 2030 to six per cent in 2050.

Figure 2

STEPS and APC scenarios for bitumen consumption



BBC in net-zero emissions scenario by 2050

In the IEA *Net-Zero Emissions Scenario (NZE)* by 2050, two-thirds of total energy supply in 2050 comes from wind, solar, bioenergy, geothermal and hydro energy. Solar becomes the largest source, accounting for one-fifth of energy supplies. Fossil fuel use falls drastically, and no new oil and natural gas fields are required beyond those that have already been approved for development.

Achieving the goal of net-zero emissions results in a dramatic reduction in the combustion of liquid fuels derived from fossil sources, reducing the global demand for crude oil for manufacturing gasoline and diesel fuels. Refinery runs fall by 85 per cent between 2020 and 2050. Refiners are used to adapting to changing demand patterns, but the scale of the changes in the net-zero scenario are unprecedented and inevitably lead to refinery closures. Crude oil continues to be used as a raw material for manufacturing a wide range of non-combustion products, either because it is very difficult to replace, or because

of favourable cost, performance and life-cycle emissions in comparison to feedstocks from renewable sources.

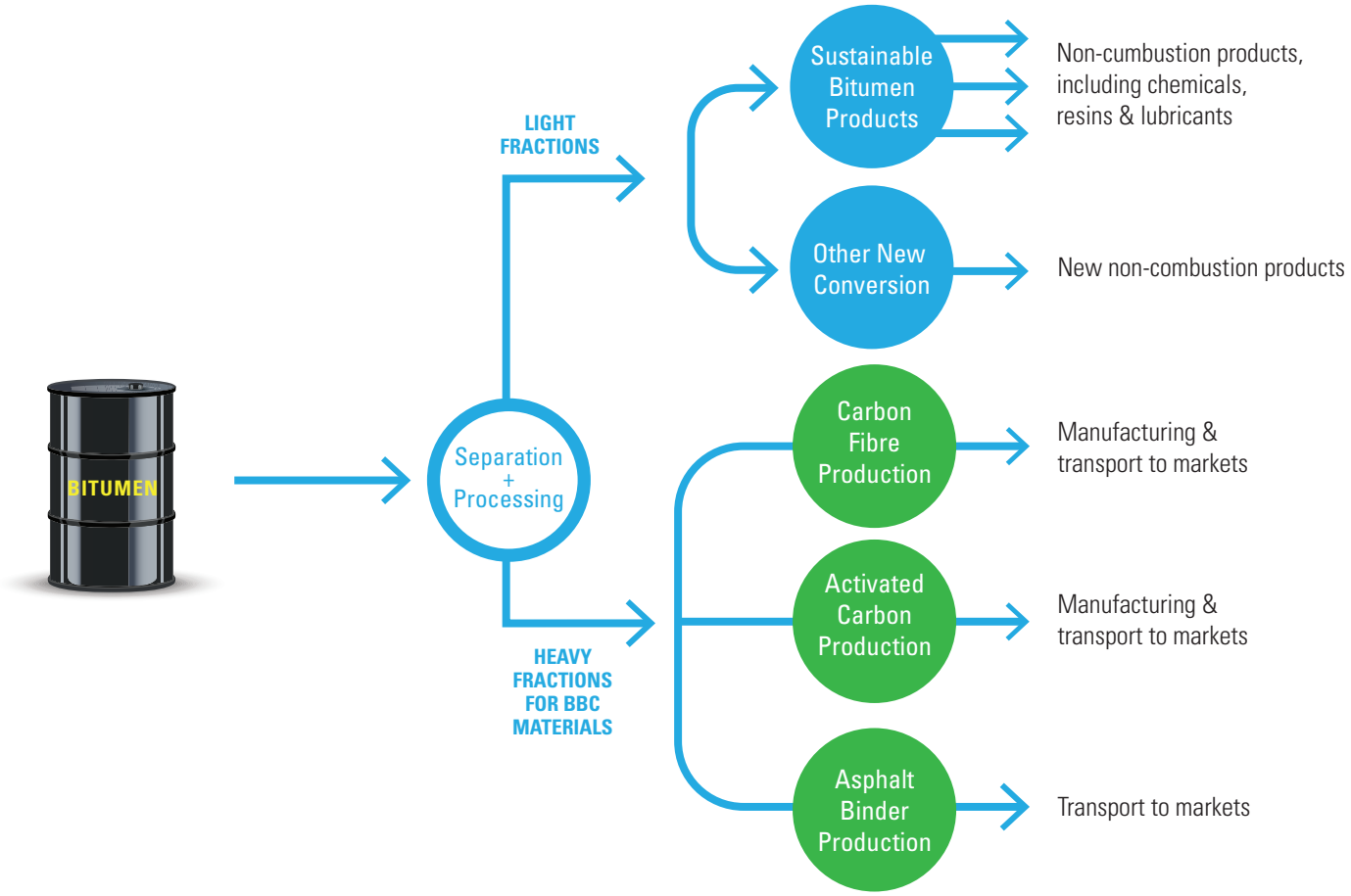
In our analysis, the dramatic reduction in demand for gasoline and diesel coupled with large-scale refinery closures would create tremendous opportunities and demand for BBC products.

- Energy efficiency would be an essential part of net-zero scenario. BBC products would be fundamental to energy efficiency, from carbon fibre for lighter vehicles to fibre-reinforced concrete.
- Solar PV capacity would increase 20-fold between now and 2050, and wind power 11-fold This would create a tremendous market for carbon fibre for wind turbines and activated carbon for energy storage.
- With refinery runs reduced by 85 per cent, asphalt production would be less than 20 million tonnes per year. The global demand for asphalt is anticipated to be over 200 million tonnes per year between 2030 and 2050. Processing light crude oils to meet the needs of petrochemical production would struggle to satisfy that demand even with extensive recycling of pavement. As fifty per cent of bitumen can be converted to asphalt, BBC can help meet asphalt demand in a net-zero scenario. Asphalt binder from oil sands bitumen lasts two to three times longer than asphalt from light crudes, meaning lower cost and emissions to repave (BCSE, 2021). A net-zero scenario would create an opportunity to establish Alberta asphalts as globally recognized premium products. New technologies for low-cost transportation of asphalt products as solids for road-paving applications are required to make this premium product available globally.

Continued investment in production and processing of bitumen in the net-zero scenario is contingent on BBC products which take advantage of the chemical and physical properties of the components of bitumen. Sustained production also requires implementing technologies to capture or eliminate GHG emissions from field production and refining. As illustrated in Figure 3 on the next page, in 2050 the heavy fractions are the prime economic drivers for bitumen use. The light fraction of a barrel of bitumen, currently the most valuable, is no longer in demand as feedstocks for liquid transportation fuels. New technologies are needed for non-combustion and emission-free uses of these light fractions, which comprise 50 to 85 per cent of the barrel.

Figure 3

Net-zero scenario for bitumen consumption



The technologies being developed by the Alberta Innovates BBC program have the potential to convert up to 50 per cent of the barrel of bitumen to products of higher value than conventional crude oil. Improved efficiency of oil sands production and expansion of the infrastructure for carbon capture and sequestration would also be required so that the production and processing of bitumen also meets net-zero targets for GHG emissions (Scope 1 and Scope 2 emissions). The combination of net-zero production of bitumen with net-zero conversion to BBC and other non-combustion products would result in valuable products with negligible GHG impact.

Potential economic, environmental contributions from BBC

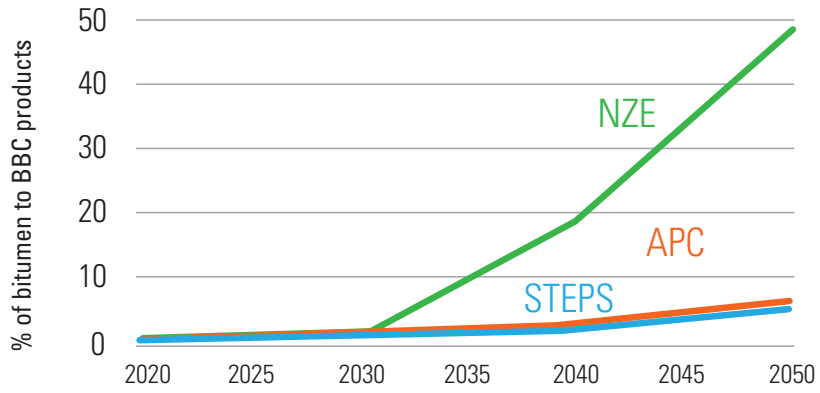
The potential contribution of BBC products to consumption of bitumen over time in the three scenarios is illustrated in Figure 4 below. Regardless of the scenario, the production of carbon fibres, asphalt and high-value carbon materials could contribute $3 billion revenue in 2030 by converting only one per cent of bitumen production.

In the STEPS and APC scenarios, the percentage of total bitumen production that would be used for BBC products beyond 2030 would remain small. Even at reduced levels of conversion, these BBC products could add almost $15 billion to Alberta's and Canada's economy by 2050. In the net-zero scenario, the conversion of bitumen to BBC products would become more and more attractive as the demand for gasoline and diesel from crude oil sources diminishes and demand for BBC products increases.

THE TECHNOLOGIES BEING DEVELOPED BY THE ALBERTA INNOVATES BBC PROGRAM HAVE THE POTENTIAL TO CONVERT UP TO 50 PER CENT OF THE BARREL OF BITUMEN TO PRODUCTS OF HIGHER VALUE THAN CONVENTIONAL CRUDE OIL.

Figure 4

BBC in IEA Scenarios: Percentage of bitumen that can be converted to non-combustion products based on three BBC products supported by Alberta Innovates



In all the above scenarios, BBC would create more economic value and reduce climate impacts from the bottom of the barrel. In the net-zero emissions and APC scenarios, the revenue from BBC after 2030 would provide the incentive to significantly expand BBC capacity over time. As demand for fuels is more and more challenged after 2030, the availability of cheap light fractions of bitumen as byproducts of BBC would encourage innovation and investment in their conversion to non-combustion products.

As the world moves toward net-zero emissions at different rates in each of the scenarios described above, the value derived from conversion of the bottom of the barrel to value-added products becomes more and more important than traditional gasoline and diesel fuels.

4: A CALL FOR LEADERSHIP AND INVESTING IN ALBERTA'S FUTURE

Achieving net-zero emissions globally by 2050 is an ambition unprecedented in human history. The timeline may be in question but the drive toward net zero is gaining momentum every day. For many, failure to achieve this goal is not an option. Net-zero emissions implies a significant reduction in the use of fossil fuels.

In the IEA and BP net-zero scenarios (IEA, 2021a; BP, 2020), fossil fuels would fall from roughly 80 per cent of total energy supply today to slightly over 20 per cent by 2050, and crude oil demand will decline by almost 75 per cent between 2020 and 2050. Climate policies announced by the governments of Canada and Alberta focus on reductions in GHG emissions and assume that bitumen can only provide energy as a fossil fuel. They do not offer a long-term vision or strategy for the oil sands industry to adapt to a net-zero world by positioning bitumen as a resource for materials rather than energy supply. Without a strategy to develop multiple end products made from bitumen as alternatives to liquid transportation fuels, the industry will likely experience gradual decline or even worse as the world moves towards net zero. The economic risks to Alberta and Canada from a potential decline of its oil and gas sector should not be ignored.

However, this does not need to be the future of the oil sands industry. In fact, it can be part of the solution. It is with such a realization that we boldly asked the question in the opening section:

> *How can the oil sands help the world reach net-zero emissions and create economic opportunities for Alberta and Canada?*

In the previous two sections, we have demonstrated that in a net-zero world, bitumen can play a critical role in making products that contribute to renewable energy production, energy storage, sustainable infrastructure, built environment and energy efficiency.

Our analysis indicates that, with the industry's *Oil Sands Pathways to Net Zero* initiative as a strong foundation to provide bitumen as a low-emission raw material, BBC could lead to significant economic development for Alberta and Canada in all three IEA energy transition scenarios. BBC could generate climate benefits and economic value both in a net-zero world and in less successful scenarios. But if it is truly successful, BBC would maximize its benefit and value in net-zero scenarios. This strategy will align the industry and Alberta's interests with the federal government's climate ambitions and its international commitments. Such benefits and values include:

- Based on BBC pathways we have identified, BBC can generate $3 billion revenue per year by 2030.
- One million barrels per day used for BBC would generate total revenue of $33 billion per year, or three times the value of bitumen ($11 billion) as feed for transportation fuels.

WE HAVE DEMONSTRATED THAT IN A NET-ZERO WORLD, BITUMEN CAN PLAY A CRITICAL ROLE IN MAKING PRODUCTS THAT CONTRIBUTE TO RENEWABLE ENERGY PRODUCTION, ENERGY STORAGE, SUSTAINABLE INFRASTRUCTURE, BUILT ENVIRONMENT AND ENERGY EFFICIENCY.

- For every million barrels of bitumen used for BBC, Scope 3 GHG emissions can be reduced by 65 million tonnes per year (compared to a base case in which bitumen is combusted). Because Scope 3 emissions occur at consumption, not all 65 million tonnes of GHG reduction may occur in Canada.
- BBC can provide more incentives for oil sands producers to reduce Scope 1 and Scope 2 GHG emissions in oil sands production by creating a long-term future for bitumen in a net-zero economy.
- Alberta can provide low-cost BBC products to manufacturing complexes and infrastructure needs across Canada, increasing their competitiveness.
- We can attract ESG-minded investors to Alberta.
- We can generate significant climate benefits in downstream applications of BBC products. Although it is still being quantified through an LCA analysis, the life-cycle GHG emission reduction due to BBC products deployment would likely be in the order of hundreds of million tonnes a year.

BBC is a disruptive initiative. It won't happen on its own, and inaction could result in losing significant components of the value chain to other jurisdictions with heavy oil (e.g., Venezuela) or manufacturing expertise (e.g., U.S. and China). Government support through leadership, policy direction and investment is needed to make BBC an economic engine and a climate solution for Alberta and Canada. The development of SAGD in the 1980s and 1990s provides a great lesson (Hastings-Simon, 2019). The creation of the Alberta Oil Sands Technology Research Authority (AOSTRA) in the 1970s and subsequent development of SAGD were not supported by the conventional oil industry at the time. However, then-premier Peter Lougheed had the foresight to prioritize the development of an innovative in situ recovery method. Lougheed's tenacity and faith in the disruption/breakthrough approach led to successful testing of the SAGD technology and the eventual creation of today's multibillion-dollar in-situ oil sands industry.

The lessons learned nearly half a century ago can still stand Alberta in good stead even though the challenges for the oil sands and the province look nothing like they did in the 1970s (Hastings-Simon, 2019). As Lougheed clearly understood, public investment is most impactful on innovative and disruptive technologies where private industry cannot or will not invest. Significant investment of public money in innovation is vital to unlocking Alberta's economic growth. This investment must play a role in future policy if the province's economy is to grow and diversify as the world advances toward net-zero emissions.

SIGNIFICANT INVESTMENT OF PUBLIC MONEY IN INNOVATION IS VITAL TO UNLOCKING ALBERTA'S ECONOMIC GROWTH. THIS INVESTMENT MUST PLAY A ROLE IN FUTURE POLICY IF THE PROVINCE'S ECONOMY IS TO GROW AND DIVERSIFY AS THE WORLD ADVANCES TOWARD NET-ZERO EMISSIONS.

We call on the Government of Canada to take advantage of the transformational opportunity Bitumen Beyond Combustion presents. BBC is a unique opportunity to unite economic interests with climate benefits for the common good. Achieving the greatest economic potential and climate benefits BBC can offer will require leadership and strategic investments. Through Alberta Innovates, the Government of Alberta has taken a leadership in BBC development. However, BBC should be a national program because its economic impact and climate benefits will reach beyond Alberta's boundary and into whole country. The federal government should create a BBC program and invest in BBC in three phases (Figure 5 on next page):

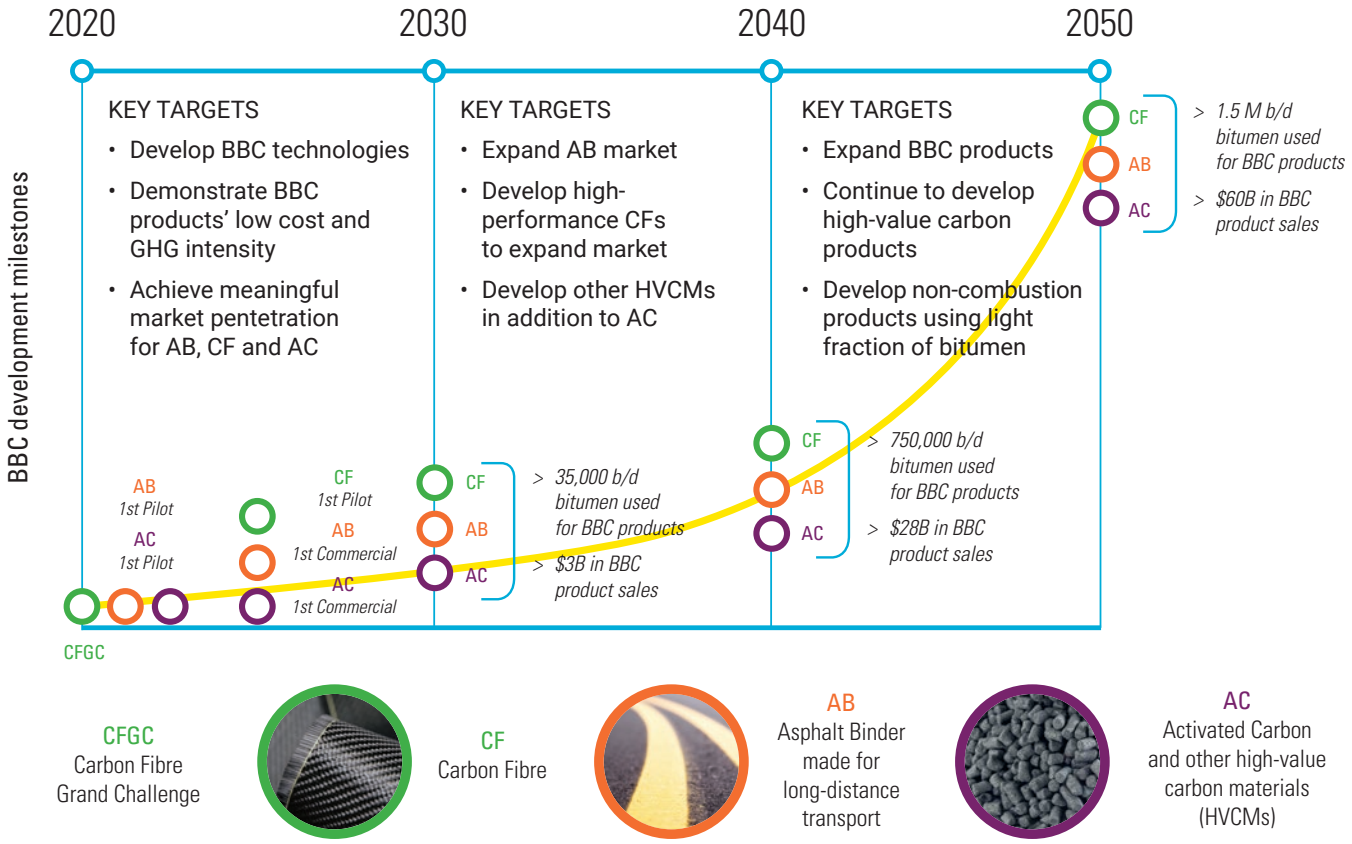
1. BETWEEN NOW AND 2030, focus would be on development and commercialization of carbon fibre, asphalt binder, and high-value carbon materials technologies; and would support R&D facilities, user networks, and highly qualified people to support the market use of these BBC products. The goal would be to use more than 35,000 barrels/day of heavy fraction bitumen for BBC and to generate a $3-billion industry by 2030.

2. BETWEEN 2030 AND 2040, the focus would be to expand the asphalt binder market, develop high-performance carbon fibres to expand the market, and develop other high-value carbon materials (other than activated carbon). The goal would be to divert more than 750,000 barrels of heavy fraction bitumen per day for BBC and to generate a $28-billion industry by 2040.

3. BETWEEN 2040 AND 2050, the governments of Canada and Alberta would invest in technologies for non-combustion or emission-neutral use of the light fraction of bitumen. The goal would be to have 100 per cent of bitumen reach net zero from production to consumption by 2050. More than 1.5 million barrels/day of the heavy fraction of bitumen would be used for BBC and a $60-billion industry created by 2050. If non-combustion products could be developed to fully utilize light and heavy fraction bitumen, even more value could be generated.

Figure 5

Development roadmap and targeted milestones for a joint BBC program in Canada



Significant investment will be required to achieve the milestone targets described above. The most critical investment is between now to 2030. The early investment should be made by governments. With success of BBC product development and commercialization, private investment will drive much of technology and market development post-2030. Investment should ramp up from $10 million/yr in 2022 to $100 million/yr after 2025, with total investment of $600 million between 2022 and 2030. A joint BBC program can leverage existing infrastructure and expertise at Alberta Innovates and Natural Resources Canada. A steering committee consisting of senior federal, provincial and industry officials could provide oversight to the joint program, making public investment fully accountable. Industry participation will include bitumen producers, manufacturers and end users.

There are several policy mechanisms that should be considered to accelerate commercial deployment. The first is intellectual property (IP) ownership and management. Through AOSTRA, the Government of Alberta owns the IP for SAGD. A small, non-exclusive licence fee is a critical success factor for wide deployment of the SAGD technology. For BBC, the challenge is even greater and a cohesive IP policy will need to be developed.

Other policy requirements relate to investment attraction. In BBC, value addition to heavy fraction bitumen may occur anywhere in the world if it makes business sense. The governments of Alberta and Canada need to develop policies that will ensure Alberta and Canada maximize the benefits of the BBC value chain.

The Government of Alberta's leadership in SAGD development in the 1980s led to a multibillion-dollar industry and created thousands of jobs across the country. BBC could be another transformational opportunity for Alberta and Canada.

If successful, BBC can create an unprecedented economic opportunity for Alberta and also help Canada to reach its net-zero emissions ambition. Furthermore, BBC could contribute to the global quest for a net-zero world.

It is our responsibility to turn this vision into a reality.

IF SUCCESSFUL, BBC CAN CREATE AN UNPRECEDENTED ECONOMIC OPPORTUNITY FOR ALBERTA AND ALSO HELP CANADA TO REACH ITS NET-ZERO EMISSIONS AMBITION. FURTHERMORE, BBC COULD CONTRIBUTE TO THE GLOBAL QUEST FOR A NET-ZERO WORLD.

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> Three million barrels per day of fuels generated from bitumen releases approximately 492 MT of CO_2 upon combustion. Using direct air capture to remove this amount of CO_2 from the atmosphere would require approximately 180,000 GWh of electricity (approximately 20 GW of continuous power year-round). For reference, wind production in Alberta in 2020 generated approximately 6,000 GWh of electricity. Direct air capture would also require 2.58 billion GJ of natural gas, which would require 22 days of the entire volume of U.S. and Canadian natural gas production.

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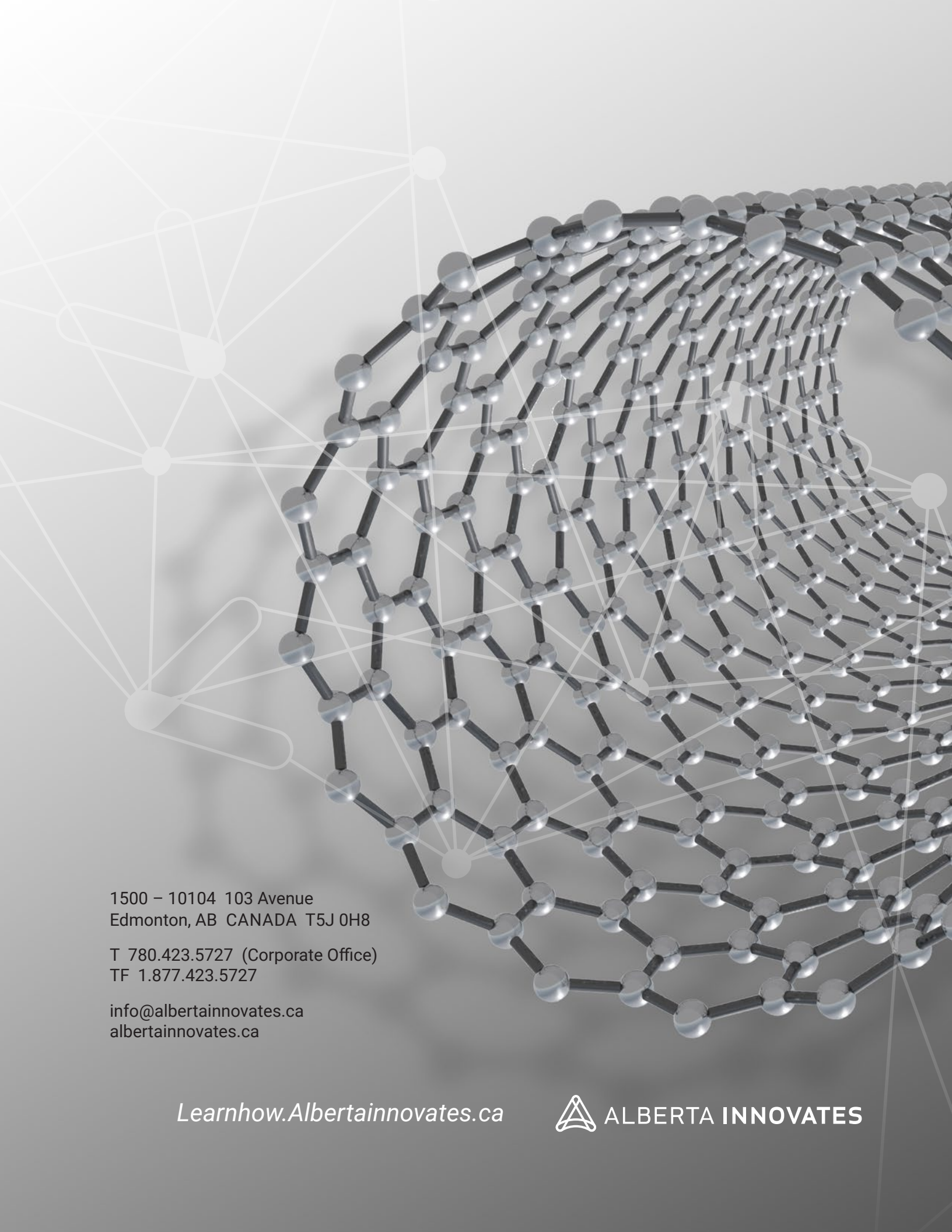

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