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AN OVERVIEW OF **GENOMICS** IN **BRITISH COLUMBIA'S** ENERGY SECTOR

Genome BritishColumbia

Leading ▸ Investing ▸ Connecting

2018 Revision

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Executive summary

British Columbia's abundant oil and natural gas reserves have enabled the development of a diversified energy sector with immense potential for growth.

BC currently produces 30 per cent of Canada's natural gas and its reserves of unconventional gas are the second largest in Canada[i]. The responsible and sustainable extraction of BC's traditional oil and gas resources, and production of Liquefied Natural Gas (LNG) and Natural Gas Liquids (NGLs), are vital economic drivers for the province, and are part of a transition to a clean tech, low-carbon economy. The sector contributes $9.4 billion to BC's GDP and 4.4 per cent to the Canadian GDP[ii] and the oil and gas industry provides 67,000[iii] direct and indirect jobs across the province; the foundation for many rural communities. The sector also provides social and economic benefits to numerous indigenous communities who choose to partner with industry and government on energy infrastructure projects.

Energy extraction and transportation activities, with their large-scale fuel and infrastructure requirements, pose risks to surrounding environments including endangered species, remote communities, and unique cultures. With global energy demand forecast to increase, particularly in developing countries, the sector must balance the growth of oil and gas economies with the responsible development and marketing of non-renewable resources. To remain globally competitive in the long term, it is imperative that the sector reduce production costs and environmental impacts by adopting innovative technologies. Opportunity lies in an improved understanding of the social and environmental effects of industry activity, and on the development of risk mitigation, monitoring, and disaster response tools.

In this challenging context, genomics is emerging as a promising technology to position BC as a world-leader in clean tech development, support the provincial transition from conventional to unconventional oil and gas safely and sustainably, and ensure Canada meets it national and international emission reduction targets. Genome BC's investment in genomics has resulted in the development of tools to improve the efficiently of hydrocarbon recovery and extract energy from wood fiber waste streams – both significant steps to reduce industrial carbon footprints.

This document lays out a strategy for expanding on previous Genome BC investments in genomics-based research to improve the productivity and sustainability of the energy sector in BC[iv]. The overarching goal of Genome BC's energy sector strategy is to distill knowledge of the challenges and opportunities facing the sector; the previous investments, results, and strengths; and the priorities of all stakeholders relevant to the sector, into an actionable set of next steps.

1. Importance of BC's Energy Sector

Between 2016 and 2026, the oil and gas industry is predicted to generate $268 billion dollars of impact on economy, creating 10,000 jobs throughout the province[v]. BC's resource sector was initially developed around oil and gas deposits, but today, natural gas resources —both conventional and unconventional— make up most of the sector. BC produces around 130 million cubic meters of natural gas each day and holds Canada's second-largest unconventional gas reserves. Current estimates predict there is potentially 3,400 trillion cubic feet (Tcf) of shale gas in the province: the raw material to feed a significant LNG industry. BC's position on the Pacific coast makes it Canada's gateway to international energy markets, particularly Asia, and as a result BC has established significant transportation infrastructure and new pipelines are proposed.

BC's Ministry of Energy, Mines, and Natural Gas currently projects that LNG exports from BC could generate $1 trillion in economic activity by the year 2046[vi], providing the necessary pipelines and LNG infrastructure projects are constructed. Apart from the sale of energy resources, the province benefits from significant capital investment that dwarfs those from the utility, transportation, and manufacturing industries[vii]. The BC economy also benefits significantly from revenue and royalties generated by energy-related operations on crown land, funding infrastructure and government services and contributing to the economic prosperity of the province[viii]. Social acceptance of these initiatives depends on demonstrating the economic and environmental sustainability of a clean, modern energy sector. Engagement and revenue sharing agreements with First Nations are critical to the development of energy infrastructure projects throughout the province. Nationally, *The Pan-Canadian Framework on Clean Growth and Climate Change* outlines the steps Canada's leaders will take to grow the economy while transitioning to a low-carbon future, reducing emissions, and building resilience to adapt to a changing climate. For the energy sector, this means leveraging technology and innovation to seize export and trade opportunities for Canada, which will allow BC to become a leader in the global clean growth economy and will also help bring down the cost of low-emission technologies. The BC Ministry of Natural Gas Development's *2017/18 – 2019/20 Service Plan*[ix] aims to grow a globally competitive LNG export industry; cultivate a competitive upstream natural gas sector attractive to investors, and increase the responsible export of energy resources and open new markets

> 'Energy' refers to a range of extracted, naturally-occurring raw materials used to generate power. This document/sector strategy covers the extraction, transformation, transmission, and distribution of BC's 'traditional' extractives/fossil fuels: crude oil, natural gas, and natural gas liquids.

BC's energy sector directly employs 20,400 people[x], and nearly twice that many indirectly in drilling, maintenance, supply, construction, and corporate and transportation industries. BC also hosts a network of energy specialists in government, academia, and industry working to monitor cumulative society impacts, environmental impacts, water, air and seismicity.

Within the province, the industry is transforming as conventional reserves decline and unconventional reserves are developed, in the form of tight or shale gas, become increasingly accessible and economical to extract using new technologies and the application of new knowledge. Clever and efficient water use, and the evolution toward natural gas liquids, means a growing and regulated industry for the province.

This strategy is intended to outline a path to support development and application of genomics to address sector challenges and opportunities. As the energy sector shifts towards natural gas—a cleaner energy source with lower greenhouse gas emissions than oil — genomics can help the industry by developing tools to monitor and remediate environmental impacts and to improve productivity and sustainability of existing extraction operations. Genome BC promotes innovation in this and other sectors by working to understand sector challenges and opportunities and facilitating ongoing partnerships between researchers, industry, government, and Genome BC to address challenges or realize opportunities.

This strategy provides an update of the areas of focus consistent with the priorities identified in the 2013-2014 Genome BC Genomics Strategy and is developed in consultation with sector stakeholders since that time. It is designed to complement and align with existing industry, government, and sector strategies.

BC's Oil and Natural Gas Resources

The Canadian energy oil and gas sector has historically been concentrated in Alberta, however, significant hydrocarbon resources have been discovered in northeast BC and offshore, and a significant energy sector has developed around these resources over the last 70 years. Once centered on crude oil and natural gas, the development of technologies to access hydrocarbon resources from unconventional sources (e.g. tight, coalbed, and/or shale gas), has changed the sector over the years and dramatically increased the supply of natural gas in BC and around the world. BC's natural gas production increased by 45 per cent between 2009 and 2015 and is the dominate resource in the sector today (80 per cent4).

There are four major unconventional gas regions in Northeast British Columbia: Horn River Basin, Liard Basin, Cordova Embayment and the Montney play region[xi]. The Montney accounts for 56 per cent of the 53.2 Tcf of the province's natural gas reserves and will be a major source of future supply. Over 90 per cent of all wells drilled in 2015 were in the Montney Play[xii].

While the natural gas sector has been steadily expanding, BC's oil production has declined since 1998 when it peaked at 2.7 million barrels per day (bpd) then dropped to 1.2 million bpd in 2015[xiii]. This drop in production was the result of dwindling exploration spending, which has dropped the oil reserve-to-production ratio in the province to 14 years. Without future reserve discoveries, the province has just 14 years of oil left[xiv]. The drop in crude oil price in 2014 has contributed to the industry's conservative approach, halting projects, and reducing exploration. Market pricing is currently one of the largest hurdles for BC's oil and natural gas sector, and in this market companies will look to cost-cutting using innovative tools to lower the bottom line and reach new markets.

Accessing overseas markets requires significant investment in the development of pipelines, processing facilities, tanker ports, and other supply chain infrastructure. Advances in LNG compression technologies have made it economically feasible to transport LNG by ship, which has disrupted the conventional pipeline model and increased the global trade of natural gas. BC is Canada's best-positioned province for access to global markets, specifically Asia where demand for oil and gas is high.

Most of BC's reserves and current resources lie beneath crown land where access and development of these resources is overseen by various government agencies. The British Columbia Oil & Gas Commission (BCOGC) regulates the sector, balancing the exploration, development, extraction, and

reclamation of provincial resources with the social, environmental, and economic impacts. The commission was created in 1998 by the Canadian Association of Petroleum Producers (CAPP) and BC government to facilitate investment and support the development of the provinces' vast reserves.

With an energy sector focussed on natural gas—the world's cleanest-burning fossil fuel—and proximity to global markets, BC has an opportunity to be a global leader in secure and sustainable development of non-renewable energy resources. With numerous deposits contained in shale and other fine grained sedimentary rocks, realizing this opportunity will require the integration of innovations along the value chain; from technologies to aid exploration and access, tools to improve productivity and transportation, to management of the environmental footprint.

1.1 Resource extraction

BC's hydrocarbon deposits contain a mixture of resources that have formed over millions of years, separating into gases, liquids, and oils, each requiring specialized technology to be extracted and refined. Conventional resources are those in porous rock that have high permeability and allow free-flow of gas and oil, which can be pumped or sucked up to the surface. These resources have largely been consumed in North America and the energy sector has been forced to develop resources that require more energy and technology to reach.

Technological developments have allowed for the cost-effective extraction of unconventional resources, such as tight gas sands, coal bed methane, shale gas and gas hydrates. BC is a significant national and international producer of natural gas; the second-largest in Canada. In 2010, BC's unconventional gas production surpassed conventional and is the source of 80 per cent of the province's gas production, the vast majority of which is developed in the Montney play[xv].

Unconventional resources, listed in increasing difficulty to extract are tight oil, coalbed methane and shale gas. These hydrocarbons are trapped in fine-grained geological formations that must be broken to allow the gas and liquids to be extracted to the surface. Fracking, developed in the 1940s, is the application of pressure to hydraulically fracture rocks to increase permeability – a process that has allowed for the development and extraction of resources that were previously thought to be economically unfeasible to access. Different technologies are used to extract lighter resources, such as natural gas re at the top of a deposit, or heavier oils at the base.

Natural gas is comprised mainly of methane, referred to as dry-gas, and can contain gaseous impurities such as ethane, propane, butane, pentane, and condensates that are valuable bi-products known as Natural Gas Liquids (NGLs). Nearly all NGLs produced in BC are transported to Alberta to be used in solvents and diluents in oil sands operations, while in other parts of the world they are the feed stock for the plastic and chemical industries.

Prior to transporting natural gas, it must be purified in a refinery where NGLs are removed, as well as unwanted impurities, such as hydrogen sulfide (H2S). Sour gas is any natural gas that contains H2S, a highly toxic, flammable, and corrosive substance that, if not removed, will damage downstream steel pipes, pumps, and infrastructure. Sulfur-reducing bacteria living in oil and gas reservoirs, or introduced by fracking equipment, can contribute to the formation of H2S and increase the cost of extraction and refining.

Oil is a dense hydrocarbon ranging from light crude oil to viscous bitumen that is the foundation of the energy industry and the feedstock for asphalt, fertilizer, pharmaceuticals, and chemicals. BC produces less than 2 per cent of Canada's crude oil, and most of this oil is considered unconventional. As BC oil operators adopt new technologies, previously uneconomical or technically impossible deposits will become accessible.

1.2 Infrastructure and Transport

Recovering oil and gas requires continual exploration and the development of new resource extraction infrastructure as older wells are exhausted and decommissioned. In 2015, BC extracted natural gas from 9,000 wells, increasing natural gas production by 4.2 per cent. At the same time, oil dropped by 2.8 per cent and liquid petroleum gases increased by 20.7 per cent from the previous year[xvi]. Increases in supply require equal investments in transportation infrastructure that carry hydrocarbons from the far north of the province to refineries and markets at the south of the province and across the country.

In 2016, 33 per cent of natural gas from BC was exported to the United States, 56per cent was delivered to parts of Canada and the remaining 11per cent was consumed within BC[xvii]. The 43,584 km[xviii] of existing pipelines crossing the province carry natural gas, water, crude oil, high vapour pressure gasses, and other chemicals to terminal stations and ports for export.

Corrosion of pipes, values, and seals can lead to failures such as leaks and the spillage of hydrocarbons, which are harmful to the environment. Microbial Induced Corrosion (MIC) is estimated to be responsible for 34per cent of corrosion, which poses a significant risk to life and the environment, as well as being a significant expense to clean up and repair[xix]. Marine transport infrastructure and tankers also face significant corrosion issues, all of which erode profit margins and BC's capacity to reach new markets. As the western gateway to Asia and other global markets, BC's unique position for access to natural gas markets is expected to grow by 49per cent by 2040[xx], but to do so requires the development of local capacity and transport infrastructure.

For BC to meet the rising global demand for natural gas, LNG compression plants, ports and tankers are needed. As of September 2017, Natural Resources Canada listed 16 active LNG projects that have the potential to broaden BC's export market. Four LNG projects had been cancelled. Advancements in technology have allowed producers to access unconventional resources, increasing supply and dropping the price, a factor which has led to a downturn in LNG infrastructure investment.

These large-scale projects will increase tanker traffic dramatically. The expansion of Kinder Morgan's Trans Mountain Pipeline and the Westridge Marine Terminal was permitted to move forward in 2017 and will see an additional 29 additional tankers passing through Vancouver Harbour carrying diluted bitumen to overseas refineries[xxi]. Such an increase in traffic will lead to minor spills, and potentially increases the risk of a larger spills along the BC coastline. This issue is a concern for some residents of BC who feel that this increase in tanker traffic is an unacceptable risk to sensitive and rare wildlife habitats along the BC coastline. Investment in hydrocarbon degrading technologies in marine environments is a must to protect BC waterways and for the industry to earn social credibility.

1.2 Environmental Reclamation & Greenhouse Gas Management

The environmental impact of the hydrocarbon sector in BC is focused on managing the carbon footprint of the province and the impact these projects have on water and marine environments. Expected emissions from BC's natural gas, utilities, transport, and buildings is projected to reach 68 million tonnes in 2030. This is an 8 million tonne increase from 2016, and is the main contributor to the BC's carbon footprint[xxii]. Managing the expansion of the natural resources sector while controlling emissions will require investment in technologies to monitor and capture greenhouse gases (GHG)and identification of opportunities to sequester and store GHGs.

As the majority of BC's gas wells shift to unconventional operations, there will be a requirement for larger quantities of water and energy to access the trapped hydrocarbons. This water is mixed with chemicals to facilitate recovery of oil and gas. Removing larger quantities of water from aquatic environments can have downstream effects on wildlife and downstream biospheres. Water, which is brought back to the surface from the well, requires decontamination prior to being released into the environment. The development of remediation tools to retreat water and clean-up decommissioned well sites will shape the industries expansion in the province. Current social and political pressure around the impact of LNG and oil operations in the province has stalled projects, or resulted in closure.

To earn public trust, the oil and gas industry must prove they have the tools, capacity and motivation to prevent hydrocarbon spills, protect the environment, and the people of British Columbia.

2. Sector Challenges and Opportunities

To realize the many opportunities for growth and investment in the sector, it is necessary to understand the challenges facing BC's energy sector in the context of a fluid socio-economic and geo-political environment. The overarching challenge is to increase productivity of BC's oil and gas operations and transport infrastructure, while lowering production costs, adding value and reducing the environmental impact. Realising these opportunities to build a more sustainable sector will deliver benefits to British Columbians now and in the future.

Market access and pricing

Growth of BC's energy sector is intricately linked to both pricing and access to market. Peak natural gas prices in 2014 spurred exploration, projects, and pipeline development to access new markets. However, declining prices for natural gas and crude oil have negatively impacted markets, exploration and project investment. Global demand for energy continues to grow year over year, but at a slightly slower pace (1.3per cent/year vs 2.2per cent/year from 1995-2015)[xxiii] due to increases in energy efficiency. Demand for natural gas is expected to grow at a faster pace (1.6 per cent/year) until 2022 as global economies rebalance their energy portfolios, stepping away from coal and taking advantage of cheap and transportable LNG[xxiv]. For BC, access to global markets is critical to the growth of the sector, and hinges on the development of pipeline projects and LNG facilities, both of which face heavy social opposition and are not feasible at current LNG prices. The development of technologies that address public concerns, provide greater environmental monitoring capacity, and reduce permitting times are critical for the continued development of the energy sector in BC.

Productivity and operational efficiency

The primary challenge for BC's abundant non-renewable resources sector is extracting, processing, and delivering hydrocarbons to end users safely, at the lowest cost, while managing the carbon footprint of the industry. Identifying untapped resources and expanding current reserves in the northwest to feed supply will be important, but efficient management of water, energy, and human capital is critical to becoming a global leader in the sector. Key areas for efficiency and cost improvements in the hydrocarbon industry are corrosion control in pipelines[xxv], bio-control of sulfate reducing bacteria in oil and gas wells to prevent souring, and identifying new deposits through the use of bioprospecting, bio-fingerprinting, and pollution tracing. Optimizing operational and extraction efficiency (e.g. with microbial recovery) in tandem with the reduction of H_2S well production by sulfate reducing bacteria (SRB) can reduce wear and tear on equipment and increase plant safety.

Environmental sustainability

The oil and gas industry, with its large fuel and infrastructure requirements, poses significant risk to surrounding environments, such as nearby ecosystems, ecological communities, water resources, remote communities, and cultural sites. These risks give rise to further challenges with respect to public perception and acceptance. Improved capacity to meet and exceed regulatory requirements can de-risk oil and gas operations that are often held up by permitting delays and social interventions. Tools to capture high-quality baseline environmental and genomic data provide a deeper understanding of ecological system that can be used to improve remediation and restoration efforts, reduce the cost of monitoring programs, and shorten permitting and regulation timeframes.

Genomics monitoring tools are also critical for understanding the complex chemical reactions that take place in tailings ponds and wastewater enclosures. Waste remediation and water treatment using active bioreactors or passive wetlands rely on bacterial communities to reduce the cost and increase the effectiveness of operations. Bacterial communities are an invaluable tool when used in disaster response as a bioremediation tool to clean up terrestrial and marine spills.

Innovation

The application of genomic solutions in the oil and gas sector is gaining momentum as companies include genomic tools to monitor the biological components of their operations. However, it is often difficult to understand the implications of the data from these living systems, and many consider the data as lacking robustness, sensitivity, and transferability to other operations. This may hinder innovation in the sector and there is a need to address these hurdles. Innovative methods to generate and share complex system data may inform a fuller understanding of complex ecosystems and provide a platform for innovation within operations. Additional opportunities exist for the application of genomic tools and collection of data that span many industries (pharmaceuticals, food, cosmetics, defense, mining, etc.), allowing all industries to benefit from research and development investments.

Social license

Obtaining and maintaining a social license to operate is key to the extraction industry, and a critical risk for future investment in the sector. Negative public perception of the health and environmental effects of energy projects in BC has generated significant public. For example, pipeline indecision and public concern over marine tanker traffic halted the Pacific Northwest LNG project. Improved understanding of

pollutants and their release into the environment would benefit from toxicogenomic and real-time monitoring tools, which both support decision makers and de-risk operations.

Many of these challenges and opportunities have their roots in the proximity of our non-renewable geological resources to the surrounding environment and ecosystem. As such, genomics offers potential solutions to these challenges and can help seize new opportunities. For the sector to remain globally competitive in the long term, it is imperative to diversify and adopt innovative technologies.

3. Genomics in the Energy Sector

Genomics is the science that deciphers and understands the genome – the code or blueprint, of a living organism (humans, animals, plants, microbes) – to better understand biological systems at a molecular level. In the last decade or so, the field has advanced rapidly and is increasingly becoming cost effective. The scientific knowledge and innovations emerging from genomics-driven research are unearthing solutions to a broad range of complex biological challenges, including applications in health, forestry, fisheries, aquaculture, agri-food, energy, mining, and environment.

At the same time, these state-of-the-art approaches give rise to the need for dialogue regarding societal, economic, and ethical implications of genomic information. The application of genomics in the energy sector has not captured the attention of the public like genomics in the agrifood sector, yet the energy sector has been a pioneer and early adopter of genomics technologies, particularly when it comes to biocorrosion.

Of the 3.5 million kilometres of pipeline in the world, the United States contains 65per cent, followed by Russia (8per cent) and Canada (3per cent). Corrosion costs the oil and gas industry billions of dollars each year, of which MIC is estimated to be responsible for 34per cent of industrial corrosion[xxvi]. Canada has stepped forward as a leader in MIC, funding a $7.8 million collaborative research project between the University of Calgary, the University of Alberta, and Memorial University to investigate the biochemical reactions that occur in oil and gas pipelines between carbon steel and microbial biofilms.

The use of microbes to enhance oil recovery (MEOR) is well established and has been used in many places in tertiary extraction to improve oil recovery, extending the productive life of oil reserves. Pioneered in Europe and the US in the 1980's, genomics and related technologies are providing new opportunities to increase extraction efficiencies under wider environmental conditions. Several countries, notably China and Australia, are undertaking MEOR field trials.

Environmental DNA (eDNA), a technology that detects the presence of organisms in the environment, is being used to identify bacteria living in symbiosis with certain hydrocarbons and is being developed to improve oil and gas exploration. In Canada, the University of Calgary and the Nova Scotia Department of Energy are using eDNA to identify bacteria similar to those in the Gulf of Mexico that are capable of living in or near hydrocarbons to pioneer new techniques in marine oil exploration. The development of a hydrocarbon-friendly microbe index will allow water sampling techniques to collect deep-sea microbes to be used in conjunction with modern geo-exploration techniques to find new sources of oil, and de-risk exploration efforts.

Across the sector, genomics is improving our understanding of environmental ecosystems and has found application in areas like environmental remediation. The 2010 BP Oil Spill in the Gulf of Mexico was one of the largest oil spills in history, releasing 4.1 billion barrels of crude oil. This disaster also created a breeding ground for naturally-occurring marine bacteria capable of living in and breaking down crude oil. Researchers from University of California, Berkeley discovered a new bacteria, *Bermanella macondoprimitus,* among others that display mechanisms to break down oil in marine environments. Cataloging and improving strains such as *B. macondoprimitus* through the application of genomics may contribute to the development of bioremediation tools for cleaning up hydrocarbon spills in marine environments[xxvii].

Across the sector, genomics is emerging as a promising technology to position BC as a world-leader in clean tech development, helping the province transition from conventional to unconventional oil and gas safely and sustainably, and ensuring Canada meets its national and international promises to reduce emissions. Much of the primary motivation for genomics-based research in energy stems from the need to develop tools for monitoring operational and environmental conditions. As our understanding of these conditions at the molecular and ecosystem level increases, and as the field of genomics advances, we can expect genomics to find greater and more universal acceptance in the sector.

Impact of BC investment in genomics

Genome BC has been strategically investing in the application and advancement of genomics in BC's energy sector since 2008, developing eight projects worth more than $32 million. With the support of Genome BC, researchers in BC are developing or using genomic tools to understand environmental ecosystems in and around energy operations to aid hydrocarbon exploration, manage of fracking fluids, and remediate biofuel release. With funding and support from Genome BC and Genome Canada, BC researchers have established productive partnerships with leading institutes such as the National Research Council, COSIA and partners in industry and government.

Genome BC's investment in the energy sector is relatively new and focused primarily on the discovery or early-stage applied research that is improving our understanding of environmental conditions and tool development for monitoring environmental and operational conditions. As these projects reach completion, further research is building on this knowledge and testing the tools in bench- or pilot-scale applications. For instance, information from a project to chart microbial community structure and function in hydraulic fracturing fluids at various stages of shale gas development has contributed to a multiphase project to develop effective and cost-efficient remediation technologies based on the combined activities of soil microbial communities and trees.

Other projects are laying the foundation for further work to improve the sustainability of hydrocarbon extraction and transport including souring control (less unplanned hydrogen sulfide), tailings pond modeling, and pipeline corrosion prevention.

With this foundation in place, BC is well position to develop projects focused on controlling and understanding bacterial growth in oil and gas wells, and the biochemical conditions that lead to and contribute to gas well-souring. While most new investment in the oil and gas extraction has been directed towards expanding current reserves, there are additional opportunities for investment in technologies that push the extraction boundaries on unconventional resources.

In BC, the potential socio-economic impact of these investments is significant. Beyond cost savings from improved efficiencies and reduced losses to corrosion, the wider acceptance of genomic-based tools may increase public confidence in the energy sector as the sector demonstrates capacity to track their impact, using biome monitoring tools like eDNA, as well as detect and clean up spills to mitigate serious disasters. These investments also create high-quality jobs, supporting new education needs and bring a skilled workforce to the sector.

Overall, the investment in applied technologies within the energy sector is critical for the sector to innovate and meet the demands of a changing energy market while maintaining sustainable and efficient industry operations to meet future challenges.

4. Opportunities for BC:

Creating Opportunities for Genomics in BC's Energy Sector

Genome BC has advanced several genomics projects to develop BC's energy sector and contribute to the social and economic well-being of the province. As BC looks to a second decade in the development and application of genomics in the sector, there are numerous opportunities to which it might contribute and challenges it may help solve.

Greener, more efficient production methods

Green operations are carbon neutral and highly efficient. Genomics can be used to enhance or develop novel carbon sequestration mechanisms to mitigate carbon emissions such as carbon fixation by algae, which naturally consume CO2. Through gene selection and optimization, it can be made to create value bi-products from waste factory emissions. Industrial CO2 emissions can also replace oil and natural gas liquids as a feed stock for some industries, further decreasing the total GHG emitted in specific supply chains.

Water treatment and energy consumption

Increased water restrictions for oil and gas operations require the recycling of water, which injects foreign bacteria into wells and can lead to the generation of H2S gas, a highly toxic, flammable, and corrosive gas. Understanding the biological processes at work within oil and gas wells is critical to stop the production of H2S. Harnessing underground microbes also enhances recovery. Microbial sensors provide on-site rapid analysis of water for specific contaminates, such as arsenic, and shorten water testing from weeks to hours.

Environmental monitoring

Environmental Impact Assessments (EIA) are a critical first step in the development of all resource extraction operations in BC, and take considerable time and resources to complete. Genomic-based tools like bio-fingerprinting, eDNA, and the development of ecological databases may dramatically decrease the time and resources required to conduct EIAs, as well as increase the capacity of environmental engineers to track, assess, and understand unforeseen industry impacts.

Expansive environments such as the ocean, tundra, and desserts are costly to assess, due to rare animals sightings and remote access. Passive tools such as eDNA can detect the presence or absence living creatures on a large scale for richer impact assessments and cheaper long-term monitoring costs.

Pipeline corrosion prevention

MIC poses a significant cost to the oil and gas sector, contributing to higher pipeline maintenance costs. MIC is a significant contributor to pipeline failures resulting in the escape of sour gas and hydrocarbons, which creates controversy over pipeline safety and erodes public trust. A genomics-informed understanding the formation of biofilms at the molecular level - identifying the species present and the chemistry that catalyzes these reactions - is the first step to reducing a multi-billion-dollar problem for the oil and gas sector. Bacterial controls that reduce the formation of biofilms within, bind bacteria into suspension, and prevent adherence to pipeline walls reduce corrosion, accidents, maintain costs, and improve the public faith.

Treating well souring

Canada is the fifth- largest producer of natural gas in the world and BC produces 24per cent of the marketable gas in Canada[xxviii]. Sulfur reducing bacteria create significant problems downstream. Advancing the understanding and management of these bacterial communities could save the BC oil and gas industry billions of dollars, and create technology to make the province a global leader in well-souring prevention and control. Protecting gas wells, pumps, and downstream equipment from the corrosive effects of hydrogen sulfide gas is a priority for the industry. Current industry practice does not have a test to determine if wells are souring due to bacterial processes or non-biotic thermogenic processes. Genomics could be used to develop a test to determine the cause of well-souring and a treatment to reduce H2S generation.

Mitigation of GHG emissions

GHG emissions are most commonly associated with the burning of fossil fuels, but significant bacterial-catalyzed processes are also contributing significant quantities of GHG to the atmosphere. Bacterial communities living in oil sands tailing ponds are contributing 20per cent-40per cent of the methane generated in the top layer of the pond[xxix]. Understanding the anaerobic reactions that occur between bacterial communities in tailings ponds and mitigating them can reduce methane production, a GHG gas that is eight times more powerful than CO2 at contributing to climate change.

Contaminated marine sites and hydrocarbon spill rehabilitation

The accidental spill of hydrocarbons into marine, aquatic, and terrestrial environments is a serious environmental and health issue that is unfortunately all too common. The energy industry has developed several tools to clean and remove hydrocarbons from the environment. Bioremediation tools are the newest and most promising. Algae and bacterial species have been shown to breakdown oil and other hydrocarbons, albeit slowly, in the laboratory and in the field. A better understanding of the meta-genomic profiles of these species and their interactions with hydrocarbons in specific environments is needed to speed up the reaction, improve overall

breakdown, and provide a powerful tool for the oil and gas industry to use to protect the environment and local communities.

A Roadmap for Genomics in BC's Energy sector

Genome BC is committed to the generation of knowledge and generation of tools and applications to contribute to sustainable energy solutions for BC and Canada. This commitment includes strategic investment in both the renewable[xxx] and non-renewable energy sectors. In the non-renewable sector, Genome BC is seeking to build on knowledge developed through earlier discovery-stage research to support a diversified portfolio which includes support for pilot projects to prove the utility of genomics in the sector, by working with key stakeholders to de-risk research and development investment and deliver tangible impacts in the short and long term.

4.1 Pilot projects

Within the current strategy the following types of pilot projects may be considered to provide a range of impacts that could benefit stakeholders across BC's energy sector.

Pilot Project	Impact	
	Short Term	Long Term
Using genomic tools to understand the role of microbes in recycled surface water in gas well-souring, corrosion and heavy metal leaching	Develop the best tools and practices for the oil and gas industry to manage microbial effects in upstream operations	To apply industry-wide practices to prevent or stop detrimental bacterial effects on energy infrastructure.
eDNA tools to detect oil & gas relevant species in pipelines, wells, and the natural environment	Build a library of important microbial species to the energy industry and the capacity to deploy eDNA tools in the field	Deployment of eDNA tools to monitor and control microbial effects in the energy industry and train high-quality personnel needed to support industry
Developing genomic tools to monitor ecosystems, reducing permitting times and de-risking project development	To integrate genomic tools in the field with current EIA procedures and establish industry protocols for eDNA and other genomic tool testing	The establishment of genomic tools with regulatory agencies and the reduction in time and resources needed to conduct EIAs, as well as the de-risking of project investment
The development of disaster response tools to degrade and consume hydrocarbons in marine environments	Identify and enhance marine hydrocarbon-consuming microbe's capacity to live in and breakdown hydrocarbons	The development of commercial full-scale disaster response solutions to be applied to oil spills in aquatic environments that completely degrade hydrocarbons into substrates suitable consumption by marine ecosystems

4.2 Community engagement

While cutting-edge technology opportunities and genomic applications are well known among BC researchers engaged in energy and related environment genomics, gaps exist between thinking and doing. Some. To increase the adoption of genomics-based tools by managers and executives in both the public and private sectors whose responsibilities relate to broader issues of public policy, resource management or competitiveness and achieve high impacts in industry sooner, it is important to bridge these gaps and connect these groups. Whether the gaps arose from premature promotion of genomics potential, or use of language too technical or otherwise inaccessible, it is important that the energy

sector community finds common language to understand and address opportunities. The opportunities presented by the application of genomics needs to be embraced to close a fundamental dialogue gap between providers and users of genomics technologies. To see real progress in applications, Genome BC will pursue a coordinated approach to stakeholder engagement, dialogue, and collaboration on important issues related to energy sector innovation.

5. Advancing the Implementation of Genomics

The prime opportunities for practical applications of genomics in BC's energy sector include: using genomics to optimize production, lower operating costs, and shorten permitting timelines; using bio-fingerprinting for baseline monitoring, water treatment and to trace pollution; and, to assess disaster impacts, monitor pipelines, and adapt to regulations.

To achieve these targets, Genome BC has been consulting with stakeholders not only in BC's energy sector but across Canada, as well as with international experts, to understand how genomics will continue to be applied to maximize economic and social benefits arising from various sector activities. The overarching goal of developing this genomics strategy for BC's energy sector is to distill knowledge of the challenges and opportunities facing the sector; the previous investments, results, and strengths; and the priorities of all stakeholders relevant to the sector into an actionable set of next steps.

Genome BC has developed this Roadmap to encourage the uptake of genomics in all sectors, and makes the following commitments to support the Roadmap;

- Education
    - All stakeholders: Inspiring students through education programs and empowering teachers with new education tools
    - Genome BC: Geneskool, public talks Genetalks
- Stakeholder engagement
    - All stakeholders: Bringing together and supporting the life sciences community to a reach a common vision and achieve a common goal
    - Genome BC: sector work/task forces
- Partnership Development
    - All stakeholders: Engage with partners and catalyze user-academic interactions to bridge the academic-industry gap
    - Genome BC: sector work/task forces
- Development of pilot projects
    - All stakeholders: Pilot projects demonstrate the practical and cost-saving value of genomics.
    - Genome BC: Funding for partnered, applied research
    - Genome BC: Through the development of Sector Innovation Centres, Genome BC's goal is to help build ecosystems beyond projects – as a partner with key players in the sector.
- Communicating successes
    - Genome BC: Position Genome BC and the corporate brand as an "honest broker" contributing to government policies, strategies, and regulations

- Genome BC: Share success stories in targeted publications, including Genome BC news releases and sector-relevant trade journals.

Appendix 1. Members of the Genome BC Energy Sector Advisory Committee as at March 1, 2018

- Allan Berezny, Assistant Dean, University of British Columbia
- Carlos Salas, VP, Oil and Gas, Geoscience BC
- Julia Foght, Professor Emerita, University of Alberta
- Tom Balke, Associate Director, (Development), UBC faculty of Science
- Catalina Lopez-Correa, Genome BC, CSO & VP, Sector Development
- Brandon Nichols, Genome BC, Sector Manager, Agrifood and Natural Resources

Appendix 2. List of Key Projects

UPP024: Natural Attenuation and Phytoremediation of Fracking Fluids

Total Budget: $ 353,500

Program: User Partnership Program

Project Leaders: Sean Crowe, Shawn Mansfield, UBC

Shale gas, the natural resource that feeds the Liquid Natural Gas (LNG) strategy of the Province of BC, is extracted by relatively new technologies using horizontal drilling and hydraulic fracturing (fracking). Fracking uses large volumes of water and additives to increase permeability in shale formations and boost gas flow into the wells. The ultimate fate of additives and shale derivatives and their effect on the well environment, surrounding groundwater, and soils are not well understood. There are concerns about the environmental impacts of potential spills/releases of additives or fracking fluids during routine shale gas extraction operations. BC Oil and Gas Commission (BC OGC) is partnering with Progress Energy, and two academic researchers, Sean Crowe and Shawn Mansfield to create new knowledge on the attenuation and remediation of key contaminants associated with shale gas development.

Bio isolating microorganisms that are living in and near fracking sites and sequencing their genomes, the team will look for genes that allow microbes to exist in acidic, toxic environments that kill many other species. Some of these species will be capable of not just living in such a harsh environment, but also sustaining themselves on the fracking fluid, breaking it down for other consortia members to utilize in their metabolic cycles. Long term goals of this research is expected to lead to effective remediation of contaminants at reduced costs, while meeting regulatory guidelines based on objective, scientific data.

UPP008: Microbial community structure and function in hydraulic fracturing fluids associated with BC shale gas reservoirs

Total Budget: $436,510

Program: User Partnership Program

Project Leaders: Steve Hallam, Sean Crowe, UBC

Shale gas extraction of natural gas faces many problems that naturally occurring and introduced bacteria can contribute to, which result in increased operational costs, decreased productivity and human health risks. Professors Steve Hallam and Sean Crowe have established collaborative partnerships with several industrial shale gas players including Shell, Progress Energy, and Unconventional Gas Resources Canada (UGRC) to address shale gas development challenges that can be overcome using genomic technologies.

The research will apply genomic technologies to chart microbial community structure and function in hydraulic fracturing fluids at different stages of shale gas development, which in turn will inform biotechnology innovation related to operational and environmental challenges identified by the industrial and regulatory user partners. The data will be used by the user partners to improve production practices and surface water management strategies.

SOF153: Genetic Engineering for Photosynthetic Proteins for Solar Energy

Total Budget: $380,743

Program: Strategic Opportunities Fund

Project Leaders: J. Thomas Beatty, John Madden, UBC

Solar power is an abundant sustainable energy source: in a single hour, the sun irradiates enough energy to meet humanity's needs for an entire year. However, solar energy is currently used to meet less than 1% of global energy needs. BC's current approaches to the energy sector are focused largely on fuels and hydroelectricity, thus cost-effective and efficient photovoltaic technologies to harvest solar energy are a key component in achieving a secure mixture of energy sources for BC.

The team is working with bacteria that create photosynthetic proteins to harvesting light, with the hope of creating a third-generation photovoltaic. They aim to demonstrate photosynthetic proteins are inexpensive, efficient and environmentally sustainable components of solar cells that will one day replace current manufactured products. Through the re-engineering of photosynthetic light-harvesting and electron transfer pathways and site-directed mutagenesis the team will potentially fill a gap by directly converting sunlight to electricity, using green components and without CO2 emission.

Appendix 3. Resources and References

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[iii] CAPP - OIL AND NATURAL GAS PRIORITIES for a prosperous British Columbia
[iv] This strategy focuses on the non-renewable sector. Bioenergy, energy made available from renewable biologically based materials like wood, agricultural waste, is an important part of a more sustainable energy sector is include in other strategies according to biomass.
[v] Oil and Natural Gas Priorities for a Prosperous British Columbia

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[xxix] https://www.genomecanada.ca/en/why-genomics/genomics-sector/mining/managing-microbes
[xxx] Bioenergy projects that utilize waste streams in the agro and forestry sector to generate energy are considered under Genome BC' sector strategies for these sectors.