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

Genome BritishColumbia
Leading ▸ Investing ▸ Connecting

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Executive summary

Primary agricultural production and food and beverage manufacturing – together known as the 'agrifood' sector - are an integral part of British Columbia's economy. BC's agrifood sector provided over 56,000 jobs in agrifood (including seafood sector workers) in 2015[i]. The BC agriculture sector – made up of nearly 20,000 farms on 2.6 million hectares of land producing over 200 agriculture products - contributed $3.0 billion to the provincial GDP in 2015, while 2,500 food and beverage manufacturing establishments generated $9 billion for BC in the same year[ii]. BC farms are the largest producers by tonnage of fruit in Canada and the second largest in greenhouse vegetables. Food and beverage manufacturing is the second largest manufacturing sector in the province in sales and in GDP[iii].

Despite promising growth domestically, the global agrifood sector is facing significant challenges related to climate change, environmental threats from invasive pest and pathogens, increased global competition, rising input costs in the food industry, labour shortages and changing demographics, growing world population, rising incomes, changing consumer demands, and less land and water for food production. For BC's agrifood sector to remain globally competitive in the long term, it is imperative to diversify and adopt innovative technologies.

Genomics has emerged as one of the promising technologies available to ensure productive plant and livestock agriculture and food manufacturing. The development and implementation of genomics technologies in this sector can; provide access to new markets through the development of new value-add manufactured food products, novel plant varieties capable of resisting pathogens or adapting to a changing climate; help protect ecosystems from agricultural impacts; preserve healthy soil, clear water and clean air; ensure the health of important microorganisms, plants, animals and human health, and; improve decision-making tools for effective monitoring, assessment, and management. Genome BC has already made significant investments in the development of genomic tools in many of these economically-important areas.

This document lays out a strategy for expanding on previous Genome BC investments in genomics-based research to improve the sustainability and productivity of the agrifood sector. Genome BC's agrifood sector strategy distills 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 Agrifood Sector

In BC, the agrifood sector is an important driver for the health, social and economic well-being of the province and its residents. The BC Ministry of Agriculture defines the agrifood and seafood sectors as including primary production in agriculture, aquaculture and commercial fisheries, and processing of food and beverages. Genome BC considers fish and aquaculture as a separate sector and the strategy for that sector is covered in a separate document.

BC's diverse and vibrant agriculture sector includes primary production from farmers, growers, and ranchers. Approximately 3 per cent or 2.6 million hectares of BC's 89 million hectares is used for food production. Agriculture is practiced throughout the province but has economic significance in many smaller, rural communities. With a total land area 2.5 times that of Japan, BC's terrain is dominated by mountain ranges and plateaus which result in distinct climactic zones and weather. Soil, water availability, length of growing season and winter conditions influence the types of agricultural products that can be produced in BC's farming communities. This creates a diverse and vibrant agricultural sector that produces of over 200 agricultural commodities for domestic consumption and international markets. BC has a reputation for providing safe, high-quality, and nutritious food for people in BC and around the world.

Since 2010, agrifood and seafood revenues have grown by over $3 billion to reach $13 billion in 2015 (including seafood)[iv]. Identified as an important contributor to BC's economy, the provincial government outlined plans in 2017 to increase agrifood and seafood annual revenue to $15 billion per year by 2020 in the *B.C. Agrifood and Seafood Strategic Growth Plan*[v]. Building on the success of the 2012 Agrifoods Strategy, a committee of industry, academic, business and sector stakeholders together mapped out the 2020 strategy to grow the agrifood economy, ensure food security and create well-paid jobs in BC. The plan is built around three key priorities: 1) increasing production, 2) driving competitiveness and 3) building markets to increase revenues in the agrifood and seafood sector.

The non-seafood agricultural and food and beverage processing components of the industry are growing annually and include' basic edible crops such as fruit, berries, vegetables, and grain; livestock products including dairy, beef, pork, poultry, eggs, and honey; value-added products such as wines and pet foods; and, non-edibles such as flowers, nursery plants, cosmetics, textiles, and nutraceuticals.

In early 2017, the Canadian Government highlighted agriculture and food as one of eight economic sectors with 'significant untapped potential' to benefit the national economy (The Barton Report)[vi]. In the report, the *Advisory Council on Economic Growth* makes recommendations to remove barriers to growth, including collaboration with the private sector, identification of high-potential sub-sectors, and development of collaborative projects to catalyze innovation.

Globally, the agrifood sector faces serious challenges. According to the United Nations, there will be 2.4 billion additional middle-class consumers by 2030, residing mostly in the Asia-Pacific region. As incomes increase, so does caloric intake, particularly from milk and meat. This will lead to an increased demand for safe, healthy, and nutritious food, and be a major driver for agricultural producers and food manufacturers worldwide.

Sidebar: BC is well-placed to contribute, with an established agricultural and food manufacturing sectors, diverse food types and value-add products, abundant natural resources, political stability, and a strong research and development network[vii].

Increasing sector competitiveness through innovative genomic solutions, combined with precision agricultural technologies and the development of new products and services will create value in the short and long-term for the agrifood industry. Genomic sciences can, and should, support and inform the sustainable development and management of Canada's agricultural and food processing sector to the benefit of its people, its natural resources, and the national economy.

Highlight text: Genomics is providing new tools to understand agriculture at the molecular level.

This strategy is intended to outline a path to support development and application of genomics to address sector challenges and opportunities. As part of the effort to promote innovation in the agrifood sector, Genome BC aims to build new partnerships and strengthen existing collaborations between researchers, industry, and government. In this regard, Genome BC is playing a leadership role to bring stakeholders together and facilitate the delivery of benefits.

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

BC's Agrifood Sector Resources and Markets

BC is the second largest province by land mass and represents four per cent of the total arable land base in Canada[viii]. Of BC's 925,000 Km^2 land area, less than five per cent is suitable for crops and horticulture production. If range land for livestock production is included the total, the agricultural land mass climbs to 30 per cent of the province's land base[ix]. However, despite the vast and rugged terrain, most growing regions have access to transportation and handling infrastructure for delivering agricultural commodities and processed food products to North American and international markets. Many have direct rail routes or highway links to transport hubs such as the seaport facilities in Prince Rupert and Port Metro Vancouver as well as regional airports with linkages to Vancouver International Airport.

The food industry focuses on activities from farm to fork. There are three main sub-sectors specific to the food industry. The primary sector focuses on activities related to agricultural production, the secondary sector involves food related processing and the tertiary sector includes businesses related to the transportation, wholesale and retail distribution and food service providers, such as restaurants. However, a successful agrifood sector also relies on access to quality land, water, and air that is essential for the growth of a vibrant and sustainable food supply for British Columbians and to open new markets nationally and globally.

1.1 Agricultural Land Reserve

Agriculture depends on the availability fertile land. In 1973, the Department of Agriculture established a methodology to inventory the amount of arable land remaining in BC for agricultural production[x]. This was in response to the impact a rapidly increasing population and urban development was having on prime agricultural land (up to 6,000 hectares lost for agriculture in the late seventies)[xi]. The Land Commission Act was introduced in April 1973 by the BC Government to protect agricultural land from for uses other than food production. An independent Provincial Agricultural Land Commission was created to develop a land use zone in cooperation with local governments to preserve agricultural land and enable farming activities. A total of 5 per cent (4.7 million hectares or 47,000 Km^2) of the province's land area essential for agriculture was protected for food production. Protected farmland can range in size from a few hectares to larger sections that cover thousands of hectares.

1.2 Agriculture: Horticulture, Livestock, and Crops

BC's agriculture sector includes primary production from farmers, growers, and ranchers[xii] on approximately 20,000 farms on 2.6 million hectares of land or less than 3 per cent of the provincial land base. The sector contributed $3.3 billion in farm cash receipts and $1.2 billion to the provincial GDP in 2015, up slightly more than seven percent over 2014. Farm cash receipts for BC's crop and livestock sectors were evenly split at $1.5 billion each. The top five agriculture products based on farm cash receipts include: dairy products, chicken, beef, greenhouse vegetables, and floriculture. BC led the nation in farm sales of blueberries, cherries, and raspberries. Bees play an essential role in BC in supporting agriculture and providing vital pollination services[xiii]. In 2015, the 1,700 tonnes of honey produced from over 45,000 honeybee colonies was valued at $17 million in farm cash receipts, and honeybees also provided $4.8 million in pollination services[xiv] The estimated number of BC residents employed in agrifood sector in 2015 based on a labour force survey was 21,000[xv]. BC is committed to ensuring its agricultural sector is sustainable, competitive and continues to grow. A key element of growth is its high quality, high value products such as its novel varieties of high bush blueberries and cherries (e.g. late season), as well as niche products such as endives, ginseng, essential oils, organic foods, and even big leaf maple syrup.

1.3 Food and Beverage processing

The food and beverage processing industry is a key contributor to the province's strong manufacturing sector and is the second largest manufacturing sector in the province in sales and in GDP[xvi]. Food and beverage manufacturing contributed slightly over $9 billion in 2015, a 9 per cent increase over the previous year. The sub-sector accounted for 2.7 per cent of the provincial GDP[xvii]. The sector employed 33,000 people in close to 2,500 establishments in 2015. Two thousand processing firms shipped over $7.6 billion of manufactured food while just over 500 beverage and tobacco processors shipped close to $1.5 billion. Meat and poultry products at 17 per cent represents the largest share of BC's food and beverage manufacturing followed by dairy (15 per cent), wineries, breweries, and distilleries (12 per cent) and seafood products (9 per cent)[xviii]. Growing segments of BC's food processing market include ethnic, organic, and functional foods, herbal and botanical products, specialty pet foods, and nutraceuticals.

1.4 Agrifood value chain

The BC agrifood sector value chain employs over 310,000 people[xix]. The majority of agrifood jobs relate to downstream sub-sectors, including wholesale and distribution, retail and beverage stores or food and beverage services, which employs over 260,000 British Columbians. In 2012, these sub-sectors accounted for over $30 billion in economic activity[xx]. To further build the domestic market, BC's Strategic Growth Plan envisions increasing purchases of BC products through Buy Local initiatives, including supporting marketing efforts to increase consumer demand in the domestic market and encourage inputs of local products in beverage and food processing and food services[xxi]. Other ways of increasing product distinction include supporting quality certification programs (e.g. appellation for wines or organic designation for agricultural products) to make the sector more competitive through the sale of higher value products.

1.5 BC Agrifood Nationally and Internationally

The BC Agrifood and Seafood Strategic Growth Plan commits to growing markets for BC agriculture and agrifood products across Canada and around the world[xxii]. At the National level, the BC government is committed to removing interprovincial barriers for agrifood products allowing increased access across the country. The recent agreement in 2014 with the province of Saskatchewan to enable direct-to-consumer sales of wine and craft spirits is one such example. Other initiatives include further development of agrotourism following the success of BC's wine industry that created close to $190 million in economic activity for BC in 2011[xxiii].

In 2015, $3.5 billion in agriculture and agrifood products were exported from BC to 149 markets across the globe[xxiv]. The United States was the most important export market receiving 72 per cent share of exports with China, Japan, Hong Kong, and South Korea together accounting for just under 20 percent. Food preparations for food manufacturing ($294 million), baked goods and cereal products ($230 million,) blueberries ($218 million), and mushrooms ($131 million) were the top exports for the agrifood sector[xxv]. Water was the largest beverage export segment, followed by fruit and vegetable juice, wine, beer, cider, and other non-alcoholic beverages.

2. Sector Challenges and Opportunities

To realise the many opportunities for growth and investment in the sector, it is necessary to examine the challenges facing BC's agrifood sector in the context of a fluid socio-economic and geo-political environment. Population growth, climate change, and resource depletion are serious global challenges facing all sectors, along with competition through globalization, and the need to increase productivity and sustainability. However, these challenges also offer opportunities to those who can address them. BC's diverse agriculture sector reflects varied climate and growing conditions. The overarching challenge for BC is to grow food sustainably in a changing climate on a stable land base, and to stay competitive globally.

Agrifood Sector in Transition

Success of BC's agrifood sector in the future will depend on a skilled workforce and the availability of agricultural land and affordable purpose-based infrastructure for manufacturing. Access to skilled labour continues to be an issue for the agrifood sector. Census data from 2011 indicated the average age of BC's farmers was 55.7[xxvi]. This challenging situation is complicated by the fact that new, younger people are not starting careers in agrifood at a time when technology innovation is impacting all facets and modernizing how food is produced and processed. There is a clear need to work with current farmers on succession planning and encourage a new generation of primary producers. The BC Government has identified the need to support labour market initiatives and develop industry partnerships to attract seasonal agricultural workers and temporary foreign workers[xxvii]. Labour training is also needed to support new entrants, youth, recent immigrants, and First Nations people to establish careers in the agrifood sector.

In addition to people, BC needs to continue building the resources and infrastructure to grow a vibrant agrifood sector. The Agricultural Land Reserve was created to ensure food security for British Columbians. However, just over 50 per cent of the protected farmland is not in production. As a result, BC's population of 4.6 million people is currently food insecure with a strong dependence on imported food from subsidized production systems like California. The situation is further aggravated by a growing provincial population and continued pressure on farmland from encroaching suburban areas at the agriculture/suburban interface, known as "agriburbia". The meteoric rise in ALR farmland prices moving in lock step with speculative suburban land costs prevents new producers from entering the agrifood sector and planned exit strategies for older farmers. The world is also getting wealthier and competition for existing food sources will only continue to increase. Draughts and fires in places such as California due to climate change will put further upward pressure on food availability and prices, adding to food insecurity in the province. New thinking on policy and agricultural measures including genomics approaches will be required to maintain if not increase food production in BC using current infrastructure and resources.

Access to markets

Globalization offers both opportunities and challenges. Domestically, agrifood is Canada's number one job creator, employing 2.1 million people and contributing 6.7 per cent to the national GDP in 2015[xxviii]. A strong domestic movement to Buy Local and BC's proximity to export markets are positives, but the sector still relies heavily on exporting the goods it produces to a single market; the United States. In addition, BC competes in international markets where prices for agrifood products are driven by global fluctuations in supply and demand.

Current efforts to renegotiate the North American Free Trade Agreement (NAFTA) with the USA and Mexico are proving challenging and creating uncertainty for future agrifood exports within North America. The province currently relies on a single export country, so the BC government must continue to build and secure international opportunities for agrifood products by working in partnership with industry to exploit new and emerging trade agreements. For instance, the Canada-European Union Comprehensive Economic and Trade Agreement (CETA) will provide access to new market opportunities and potentially expand BC agrifood products with current and new trading partners in Europe. The 28 member states have an estimated population of 510 million people and a nominal GDP of $16.77 trillion US. The renegotiated partial agreement for a Comprehensive and Progressive Agreement for Trans-Pacific Partnership was signed by 10 countries representing 495 million people and a combined economic output of $13.5-trillion (US) (excluding the United States) and, provides new opportunities to develop an international strategy to expand agrifood exports overseas to Japan and other fast-growing economies in emerging markets around Asia and the Pacific Rim. Membership in the trade agreement may quickly expand to other Asian countries such as India and Indonesia. Entering into trade agreements to open new market opportunities, however, is not without risk to supply managed commodities like broiler hatching eggs, chicken, table eggs, dairy products and turkey which are often seen as unfair trade practices. BC is also committed to supporting producers and processors to adopt internationally accepted food safety and traceability standards to ensure that BC food exports are at the highest level of quality and safety[xxix]. Continued strengthening of biosecurity and surveillance measures to reduce foreign incursions of pathogens, pests, and invasive species because of increased trade is essential to prevent interruption to supply, and ensure strong standards exists for safe food production for export markets. Highlighted text: Traceability, food safety, biosecurity and surveillance are areas where genomics can provide new opportunities.

Increasing Competitiveness

BC's smaller, more diverse agricultural sector can sometimes lack economies of scale, run into temporary labour shortages, or face sudden changes in input costs that can challenge producers and processors. Also, the majority of the 20,000 operating farms in BC rely on off-farm employment to supplement on-farm income. Small farming operations also face challenges related to capital investment to replace aging infrastructure, diversify their product offerings or to implement newer, innovative technologies that may reduce inputs and lower costs. Thus, the agrifood sector's focus must turn to producing, manufacturing, and commercializing higher margin products tailored to niche and fast-growing markets, rather than large acreage commodities that dominate production systems in the Prairie Provinces[xxx]. Building new market segments will support the economic growth of the agrifood sector in BC.

There are numerous segments where the agrifood sector can increase market share and economic growth. The '100-Mile Diet' and other similar initiatives to access and support Buy Local Program, e.g. farmers markets, organic foods, grass-finished beef. Consumers are also wanting complete assurance that products were grown using specific practices, e.g. pesticide-free, antibiotic- and hormone-free, animal welfare considerations, environmentally sustainable. Horticultural commodities for which the growing cycle has been lengthened or shortened - such as BC's late season cherries - come to market when no other supply is available, allowing for premium pricing. It can also mean the production of new crops, livestock, and food products with enhanced or unique attributes such as omega-3 fatty acids, meat tenderness or organoleptic quality of fruit and vegetables. For product processing innovation, crops and livestock can be bred for different processing systems focusing on specific traits and attributes, e.g. berry firmness for handling, storage, and shipping. Food manufacturing companies might develop unique product offerings in the alternative health food market such as meatless proteins, plant-based nutrition, and healthy snacks, resulting in larger market returns. The wine sector is improving marketability through appellation, or naming of wine varieties according to geography or other specific characteristics. The Golden Mile Bench sub-appellation was the first wine in BC branded for a specific regional terroir[xxxi]. Further consultations by an industry-led BC Wine Appellation Task Group indicated support for an appellation model in BC[xxxii]. The wine industry identified the need for mandatory certification of origin of wine grapes to ensure provenance requirements for an appellation program.

Highlighted text: For BC agrifood to remain competitive, it will be important to connect research capabilities, including genomics knowledge and technology, in BC academic institutions with industry needs to drive the next generation of commercialization opportunities.

Climate change and environmental impacts

Climate change is having a significant impact on agrifood production worldwide. The BC Agricultural & Food Climate Action Initiative was created in partnership with agriculture sector organizations, research institutions and local governments, and government agencies to address climate changes issues in BC[xxxiii]. The BC Agricultural Climate Change Adaptation Risk + Opportunity Assessment[xxxiv] identified the potential risks and opportunities of climate change on agricultural production in BC, including greater frequency and severity of summer drought and water shortages; decrease snowfall leading to less snow pack and water shortages; increased frequency of extreme precipitation events leading to flooding, erosion and soil nutrient loss; extreme weather events such as floods, forest fires, and drought; and increased pest and pathogen pressure due to winter survival and new incursions. On the opportunity side, climate change has the potential to lengthen the growing season in many regions and increase the growing range for crops. The current resiliency and adaptive capacity of BC agriculture relies on five interrelated areas, including Financial, Physical, Human & Social, Policy & Regulatory and Knowledge[xxxv]. Research, development, and technology are a Knowledge area where collaborative research between industry, government, and academia can address some of the climate change-related adaptation issues. Adaptation strategies might include developing new detection and surveillance tools against emerging pests or diseases for better crop and livestock management or developing new plant varieties or livestock breeds better suited to a changing climate or adapted to new ranges. Within BC, this could mean expanded production further north in the province and the ability to grow different crops on marginal lands.

Plant and Animal health and Product safety

There are growing concerns regarding antibiotic use in agricultural production systems and bacterial resistance to antibiotics from overuse or misuse in animal health. This has led to calls from some countries and consumers for stricter regulations for their use therapeutically and their banned use for growth promotion. There is an urgent need for the development on non-antibiotic therapeutics, preventative measures through better animal husbandry, new vaccines and livestock breeding for disease resistance. Plant health faces similar challenges due to pests and pathogens and public concern over the use of synthetic treatments, especially close to populated areas. New management strategies, effective controls, varietal development, innovation in treatment delivery systems, biological treatments and natural pest enemies were identified as potential approaches for improved plant protection and a move away from synthetic chemical applications. There is also a requirement for more rapid tests for timely, sensitive, and accurate diagnosis of foreign, new, and emerging plant and animal diseases and pests. These same tests can also detect agents of zoonotic diseases that can impact human health, assist with resolving trade disputes, and enable traceability of foodborne pathogens from environment to food to fork.

Several social trends are changing how British Columbians relate to food systems and the food they consume. There is growing consumer demand for nutritious, safe food that has been produced in a sustainable manner. Importing countries are also requiring higher sanitary and phytosanitary standards, for which BC is well-positioned and could further meet through the development and implementation of innovative technologies, processes and services for food provenance, traceability, and authenticity. Authentic claims and integrity focus on quality standards, product sources, product formulation, and elimination of product adulteration and fraud, e.g. medicinal plants, natural health products and vitamins, natural health products, olive oil and meat products. In the case of foodborne outbreaks, the ability to attribute a pathogenic agent to a specific environmental, production, or manufacturing source is important to reduce the impact on human health, e.g. norovirus, *salmonella.* Some humans become ill due to allergies or intolerances from eating certain foodstuffs, such as those that contain elevated levels of gluten (e.g. wheat, barley, rye) or lactose (dairy products). This is leading to consumers and government agencies to increasingly demanding the ability to track food and beverage from farm to fork.

Application of Innovation – Sustainability and Social License

What are the potential impacts of the latest innovations and how can they be employed in such a way to enhance rather than reduce the environmental, social, and economic sustainability for BC's agrifood sector? Today, this is a key question and early work considering these aspects can inform the development and application of such innovations and to help to recognize and reduce barriers to translation. This research can, for example, advance evidence-driven agricultural and food processing policy and regulation to articulate and quantify the benefits of new innovations.

Consumers are an important stakeholder in this debate, voicing concerns ranging from animal welfare, to climate change, to environmental issues such as the use of fertilizers, antibiotics, odour, noise, dust, and demands for water. Lack of engagement with consumers about values and perceptions of the health, environmental, social, and economic impacts of the latest technologies can sometimes limit the uptake of new technologies and products. Two-way dialogue involving all parties and addressing questions raised by the community are essential. Genome BC acts as a catalyst for discussion between industry, academia, government, and different publics and supports the development of partnerships to meaningfully address any arising questions and support priorities for sustainable innovation.

Management

Soil, water, air, and biodiversity are critically vital to an environmentally sustainable agrifood sector. Food production and processing practices can put pressure on soil, water, and air, and sometimes negatively impact the quality of these important resources[xxxvi]. In addition, smoke, odour, dust, fertilizer and pesticide applications and competing demands for water can lead to conflicts where suburbs and agricultural land intersect. There is a need to continuously improve soil, air, and water management practices to minimize the impact on the environment and humans. Effective manure management, a by-product of livestock operations, should be implemented to prevent overloading nutrients in the soil and groundwater contamination. More effective management of waste from food production and processing might include the implementation of new innovations to utilization by-products and their conversion into new value-add products or transformation into clean energy sources. Maintaining diverse and healthy microbiome, plant and animal ecosystems is important for agricultural production systems. For instance, insects and birds provide important pollination services while the soil microbiome is able to digest and recycle important nutrients for crop plant growth.

Research and development capacity

The challenge facing the agrifood sector is the industry's ability to seize emerging opportunities, address challenges and create new markets for BC products. The University of British Columbia's Centre for Sustainable Food Systems' Farm Joint Value Chain and Social Innovation Working Group has identified the need to develop a Food & Beverage Technology Centre to address a gap in research and development capacity for a pilot plant food processing facility to assist food manufacturers to become more innovative. The Centre would be a one-of-a-kind facility in Western Canada housing a state-of-the-art food and beverage processing facility, analytical laboratory, and pilot brewery. It would expand the Faculty of Land and Food System's focus on food safety and quality, offer unique academic research and training opportunities and enhance collaboration between BC food industry and the University.

Many of these challenges and opportunities are intimately associated with plants, animals, and ecosystems. As such, genomics offers potential to provide solutions to these challenges and help seize opportunities. For the sector to remain globally competitive in the long term, it is imperative to diversify and adopt innovative technologies that will allow the sector to develop unique BC products for a global market.

3. Genomics in the Agrifood 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, 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, agrifood, energy, mining, and environment. At the same time, these state-of-the-art approaches are giving rise to the need for dialogue regarding societal, economic, and ethical implications of genomic information.

Agriculture genomics employs powerful tools that combine genetics, bioinformatics and prediction models to advance agricultural food production while ensuring food safety. Pressures from population increase, climate change and reduction in arable land will require the application of genomics to ensure more nutritious food is produced sustainably with less inputs and requiring fewer resources.

Dairy breeding for milk production was the ideal model system for the early application of genomic selection (GS) in agriculture. Early gains in milk production were the result of breeding using meticulously catalogued pedigree records. Seventy-five years ago, an average dairy cow produced 5,000 pounds of milk in its lifetime[xxxvii]. Today, an average cow can produce over four times that amount. The sequencing of the bovine genome in 2009[xxxviii] has led to the acceleration of breeding cycles. A research partnership between Canada and the US exploited the available reference sequence to develop the first commercial genomic test for bovine[xxxix]. This has had a transformative impact on bovine genetics and milk production.

For many years the traditional method for testing the genetic potential of a bull was to 'prove' milk production in his daughters many years later, which took time and money. Today GS allows breeders to analyze large amounts of data in a single assay (thousands of markers across the entire genome linked to traits of interest) to predict the value of a bull's genetics and future milk production in his daughters. Incorporating genomic information in breeding has increased the accuracy of genetic evaluations of young 'unproven' bulls well before they attain reproductive age. Since the adoption of genomic testing in 2011, the use of genomic young bulls over proven sires for dairy breeding has grown to 70 per cent of the total in 2016[xl]. The genetic gain for individual traits like milk, fat, and protein yield have doubled in the five years since introducing genomics in Canada[xli]. GS is a revolutionary and disruptive technology that has transformed dairy breeding around the world. The success of GS in dairy production is impacting other livestock where genomic information is altering breeding strategies. GS is leading to improvements in meat quality, disease and pathogen resistance and expanding and ensuring diversity in livestock.

For thousands of years selective breeding was used to develop new crop varieties. Manipulating genomes through genetic crosses using existing genomic variation within the same species was exploited to develop plants with desirable traits. This approach, however, is limited to those easily measurable traits that are strongly influenced by heritability (the plant's genetics). A single or small number of genes controls these qualitative traits[xlii]. In the 1980's, selective breeding received a boost with the promise of marker-assisted selection (MAS) breeding, a method to improve the efficiency and increase accuracy to support crop improvement . MAS uses specific markers (signatures) positioned within a genome that are linked to the major genes or quantitative loci (QTL) controlling the trait of interest. Although the technology has been applied widely, the success in public breeding programs has been limited to specific applications such as disease or pest resistance[xliv]. For more complex quantitative traits like crop yield, quality or abiotic stress tolerance involve complex genetics controlled by multiple genes or QTLs with small overall effects, MAS has been less effective. Next-generation sequencing has led to a rapid drop in the cost of DNA marker development. Where MAS identifies a small number of genes or QTLs linked to markers with association to a specific trait, GS assesses all the available markers across the entire genome and links at least one marker to each QTL. All the small genetic variances that contribute to a trait can then be estimated through prediction models. However, implementation of GS requires considerable genomic resource development and important investment in infrastructure and bioinformatic capabilities currently only available for more economically-important crops, such as canola and wheat, or the private sector.

Sometimes a desired agronomic trait may not be easily discovered in nature. To increase crop variation a new approach was needed to induce or create the desired changes in plants genome. In the 1930s the application of mutation techniques that expose seeds to chemicals or radiation was employed successfully to increase genetic variation and enhance trait development for crop improvement[xlv]. Forward genetic screens are less costly to perform up-front however, the approach requires a lot more work downstream to screen a large number of plants for the trait of interest. Mutagenesis technology is still used today in crop development because there are no regulatory constraints to release new plant varieties using these methods. Early in the 1990s a more targeted gene manipulation approach was developed to create novel traits in crops.

The first example was the Flavr Savr, a genetically engineered tomato released in 1994 developed using gene silencing technology to extend the fruit's shelf-life. The tomato was never profitable and was pulled from commercial production a few years later. More recently, a Canadian biotechnology company, Okanagan Specialty Fruits, developed the first non-browning apples using gene silencing. Granny Smith and Golden Delicious varieties of apples received US and Canadian approval in 2015. Also in the nineties, several crops were genetically engineered by adding a gene from a different species (transgene) to provide a desirable trait such as herbicide tolerance, e.g. glyphosate (Roundup Ready) in soybean, canola and others; or insect resistance e.g. *Bacillus thuringiensis (Bt)* bacterium insecticidal gene in corn and cotton. There is only one example of a genetically engineered animal in production. Canada was the first country to develop a genetically engineered Atlantic salmon which grows almost twice as fast as traditional salmon. The fish has been commercialized by Aqua Bounty in the US and is approved for sale in Canada.

Recently, newer, more powerful gene editing tools that allow targeted changes within an organism's genome (without inserting a new gene) have been quickly adopted by plant and animal breeders. For example, the white button mushroom undergoes brown discoloration as a result of melanin expression from bruising or cutting. Using a new gene-editing tool, the gene controlling melanin production was silenced. It is expected that the new non-browning mushroom will have a longer shelf life and lead to less food waste. Unlike other genetically engineered agricultural products, the US Department of Agriculture (USDA) declared that the non-browning mushroom does not require regulatory approval to enter commercial production[xlvi].

In animal production, gene-editing was used successfully to 'genetically dehorn' cattle[xlvii]. Millions of dairy cattle are dehorned every year to protect handlers and producers from potential injury. This practice is a concern to animal welfare organizations and consumers alike. In Angus beef there exist natural variants in a gene called Polled that causes hornlessness. Researchers were able to create the beef allele in the Holstein dairy cow genome using gene-editing technology and reproductive cloning to reproduce hornlessness. However, today it is unclear how the USDA plans to formally regulate gene-edited hornless cattle and by extension gene-edited livestock in the future. There are some who argue that the USDA should regulate the safety of the product and not the technology employed to produce it[xlviii].

The current gold standard technology used for the detection of pathogens in foodborne outbreaks is pulsed-field gel electrophoresis (PFGE). This technique generates a DNA "fingerprint" for a bacterial isolate. Once a DNA fingerprint pattern is generated, it can be used to compare similar patterns in patient samples, contaminated food, and environments where food is produced to aid with outbreak investigations. Recently the US Centre for Disease Control (CDC) began using whole genome sequencing (WGS) to identify outbreaks. WGS provides greater detail by comparing genomes at a single base level resolution rather than the 20-30 bands in a PFGE fingerprint pattern. CDC is currently applying WGS to *Listeria* and will implement the methodology soon to other foodborne outbreak investigations involving *Salmonella*, *Campylobactor*, Shiga toxin-producing *E. coli*. WGS will improve surveillance of foodborne outbreaks and reduce the impact of those outbreaks by rapidly determining source attribution. The Canadian Food Inspection Agency and BC Centre for Disease Control are working on establishing similar WGS approaches in Canada.

Precision agriculture is working in tandem with genomic approaches to develop varieties suitable to specific environments. Innovative sensors that collect vast amounts of plant phenotypic (trait) data such as nitrate and other nutrient absorption and utilization, water transpiration from leaves and plant growth rates. Sensors are also beneficial to understand the performance of plants in specific environments by measuring available soil nutrients like nitrogen, temperature, humidity, and light. Sensors are being placed in greenhouses or collected from satellites and drones to support and accelerate breeding programs. High-throughput selection approaches are also being used to development new plant treatments. New innovations in phenotyping that are being developed include 'wearable' devices on plants and animals similar to was has been developed for humans. Similarly, sensors are being used to monitor food intake and measure feed efficiency in livestock breeding with a goal of managing production costs and reducing the environmental footprint of animal production systems.

Impact of BC investment in genomics

Genome BC has been strategically investing to advance the application of genomics in BC's agrifood sector for many years. Since 2000, Genome BC has invested $57M in 29 projects and continues to support genome researchers in BC who are addressing sector challenges and opportunities by:

developing innovative solutions for application in agrifood including detecting and preventing pests, pathogens and invasive species; understanding and adapting to climate change; licensing enforcement for new crop varieties; developing cutting-edge breeding programs in animals and crops; designing next-generation vaccines; and, creating higher value niche food and beverage products. Through funding support from Genome BC and Genome Canada, BC researchers have established productive partnerships with leading institutes at the national and international level, such as Canadian Food Inspection Agency, Agriculture and Agrifood Canada, BC Ministry of Agriculture, National Research Council, Vaccine and Infectious Disease Organization – International Vaccine Centre, Vineland Research and Innovation Centre, National Science Foundation (USA), US Department of Agriculture, l'institut national de la recherche agronomique (France), University of Georgia (US), Agrifood and Biosciences Institute (UK), and the University of Auckland (NZ).

Genome BC's agrifood project portfolio spans discovery and applied research. Much of the primary motivation for Genome BC's early investments in genomics-based research for agrifood stemmed from the need to generate the basic knowledge and necessary genomic resources. BC researchers, in collaboration with international partners, have played a key role in developing genomic resources and knowledge in economically important agricultural commodities such as sunflower, bee, grapevine and bovine. Today, Genome BC's foundational investments in agrifood combined with ongoing research internationally in genomics is driving the next stage of translational research studies. BC's researchers are well positioned to exploit genomic knowledge and tools to support industry partners in addressing challenges and seizing opportunities that have a potential to impact the agrifood sector in a tangible way.

4. Opportunities for BC

Creating Opportunities for Genomics in BC's Agrifood Sector

Genome BC's investment in several genomics projects has helped the agrifood sector learn and realize the benefits of genomics and the potential impact genomics can have on the social and economic well-being of the province. Major opportunities to contribute to BC's expanding bioeconomy exist for genomic tools in the agrifood sector, such as providing new treatments to improve plant health, decrease the costs of livestock production, and enhanced crop yields with improved resistance to pathogens, drought, and temperature variations. Genomics can also improve plant and animal health and food safety through detection and identification of pathogens. There are opportunities to develop tools to better manage the availability of new plant varieties and maintain open markets for BC agrifood exports. The application of genomics can be applied across the agrifood value chain and has the potential to create new opportunities and employment in agriculture and food manufacturing. Agrifood in BC is well positioned to take advantage of these opportunities. Several short- and long-term projects are underway in the following areas:

Access to markets

Genomics can support competitive domestic and international markets for BC's agrifood products. Until recently, strawberry plants exported to the US only required a visual inspection until in 2012 when plants exported from Canada died before they produced fruit for US growers. Routine molecular testing confirmed the origin of a viral infection to plant material grown at Canadian nurseries. Although there is now a requirement by the US to perform testing on exported plants, current molecular approaches for plant viruses are time consuming, laborious and require individual analysis for each viral species. For horticultural commodity exporters to the US, this can drive up costs. Next-generation sequencing (NGS) technology is disrupting how we detect and monitor harmful viruses. Once validated, NGS technology can perform a full metagenomics analysis of all viruses present in a single plant sample. The ability to detect all species of virus including those not routinely tested will ensure plants shipped are virus–free. NGS can be applied to other small fruits, fruit trees, grapevine and floriculture and when validated will allow freer trade in exported plants and assurances of quality product.

Climate change and environmental impacts

BC is already feeling the effects of climate change. Average temperatures are rising, and the occurrence of extreme weather events is more common. Managing these risks for the agrifood sector and ensuring food security in light of a changing climate will be crucial to the well-being of British Columbians in the future. One approach to adopt to a changing climate is to bread hardier domestic crops and animals. The use of new genomic breeding approaches through genomic selection coupled with new gene editing technologies will enable the development of hardier plants that are better adapted to new climate challenges. The sunflower is an ideal model system for studying plant adaptation to climate change as wild relatives from this family have demonstrated a unique ability to adapt to a variety of extreme environments of drought, flooding, salt, and low-nutrient stress. By investigating the molecular and physiological basis of sunflower's adaptations to abiotic stress, breeders will be able to transfer these stress resistance traits to elite sunflower cultivars. Once the genetic basis of stress resistance is identified, similar stress-adapted traits can be identified in other agriculturally important crops and implemented into these breeding programs.

Improving Plant, Animal, and Human Health

Early detection of pests and pathogens before they enter BC crops and livestock systems is critical to the economic success of producers, for maintaining open boarders for agrifood exports and assuring food security for all British Columbians. Current biosecurity and surveillance tools used to manage foreign incursions are out-dated, inadequate and reactionary. This is problematic with the increase in global trade, international travel, and changes to the migratory patterns in wild birds due to climate change. There is an urgency to move to molecular based tools developed from knowledge gained from genomic information. For instance, the current surveillance method for avian influenza (AI) focuses on testing individual wild migratory waterfowl who may carry AI. Unfortunately, this approach is time consuming, inefficient, costly and generates results that woefully underestimates the extent of AI. In a pilot study using samples from the highly pathogenic 2014 outbreak in the commercial poultry production in the Fraser Valley, genomic tools were used to detect AI in wetland sediments at a rate far greater than the current gold standard. The results of this project revealed the potential for genomics analysis of wetland sediment to serve as an early warning system for incursion of AI. The goal of current AI research in BC is to implement a new Provincial Waterfowl AI Surveillance Program using modern genomic analysis tools.

Productivity

Increasing the productivity across the range of agricultural and food and beverage products will lead to an increase in revenue for small- and medium-size businesses and provide jobs for the agrifood sector in BC. In addition, maintaining and increasing production yields are critical to ensuring food supply security for British Columbians. The domesticated honeybee is essential for key agricultural crops including many fruits, nuts, vegetables and cereals. Pollination support services from honeybees are valued in excess of

$200M per year in agricultural production[xlix]. Important investments have been made in several projects to find solutions to the loss of bee colonies from challenging overwintering conditions and ongoing incursions from pest and pathogens. Current funded honey bee research focuses on developing advanced genomic and proteomic tools that will allow beekeepers to breed bee colonies rapidly and cost-effectively that are better able to fight disease, produce quality honey, survive Canada's winters, and reduce industry's dependence on imported queens.

Application of Innovation – Sustainability and Social License
The conservation and sustainable use the planet's genetic resources for food and agriculture is guided by the Convention on Biological Diversity (CBD) and the International Treaty for Plant Genetic Resources in Food and Agriculture (Treaty). Together they ensure appropriate terms of access and benefit sharing from indigenous biological materials. Cutting-edge plant genomic technologies, including high-throughput DNA sequencing, gene editing and synthetic biology have ushered in the digital age in biology. Digital sequence information derived from the diversity of plant genetic resources has the potential to accelerate the rate of crop improvement and ensure food security. However, open source data sharing practiced in science is at odds with current thinking in the international community that access and use of digital sequence information derived from the study of physical plant resources should comply with the CBD and the Treaty. Such developments could present significant hurdles to continued access and use of plant genomic resources from countries around the world.

The Sunflower GE3LS project is working to clarify the terms of this debate and to work with the Sunflower research team to develop best practices on sharing in light of current discussions. Toward this end, the GELS project has worked to clarify the terms of the CBD and Treaty and to contribute to ongoing dialogue in the international community. A recent Comment published in Nature Plants outlines the terms of the debate and what is at stake[l].

Improved management
In Canada, the Plant Breeders' Rights (PBR) Act and Regulations provides protection for new plant varieties. In the same way new inventions are protected through intellectual property rights, plant breeders of new agricultural varieties (including rootstocks) are protected from propagation, distribution, and commercialization by unlicensed producers. Enforcement of PBR is often difficult and based on subjective evidence like a plants phenotype (visible characteristics) which in many cases are indistinguishable between varieties. NGS provides a new tool for variety identification for improved management of intellectual property rights. Developing unique genomic identifiers or DNA fingerprints will make it possible to distinguish between closely related varieties. Such genomic tools will allow auditing of plantings as well as identify potential licencing infringements. Through stronger PBR enforcement, the Canadian tree fruit and berry industries hope to reclaim lost revenue that would normally support future product development and commercialization of new varieties adapted to local growing conditions and consumer tastes.

A Roadmap for Genomics in BC's agrifood sector

Genome BC is continuing in its efforts to realize benefits of genomics across the entire value chain of the agrifood sector. After strategically focusing on foundational research early in its mandate, Genome BC will continue to transition its investments to work with industry and other end-users to pilot or take to scale genomics applications with the goal of implementing innovations in the sector that can deliver tangible benefits to companies, regulators, communities, and individuals citizens in BC and across

Canada. Strategically, this involves pursuing the application of genomics in food safety, biosecurity, and traceability throughout the food value chain, fostering sustainable agriculture, preparing for future changes in climate and operationalizing a Sector Innovation Centre for Plant Health.

4.1 Pilot projects

Within the current strategy the following types of pilot projects may be considered to provide a range of impacts that benefit stakeholders across BC's agrifood sector value chain:

Pilot Project	***Impact***	
	Short term	***Long term***
• *Ensure food quality and safety*	*Tools to assure quality and safety of agricultural and processed food products; traceability from farm to fork*	*Rapid source attribution; improved human health; continued access to national and international markets*
• *Biosecurity and surveillance to manage foreign incursions*	*Better tools and methods for surveillance of pest, pathogen, and invasive species*	*Rapid response to incursions; improved plant and animal health; continued access to national and international markets*
• *Quality assurance for agricultural exports*		
• *Environmental impact monitoring*	*Development of improved tools to better assess and manage decisions related to land, water, air quality and safety*	*Improve environmental sustainability of agriculture;*
• *Management and utilization of agricultural and food processing waste-products*	*Fostering innovation, development of new biological processes and products for consumer, industry, and sector benefit*	*Valorization of food waste-products, market diversification, increased competitiveness, and jobs*
• *Bio-factories for new products*		
• *Climate change adaptation*	*Biomarker and genomic selection technologies; breeding strategies for biotic and abiotic stress; development of traditional and biological control methods for plant and animal disease*	*Food security for BC; sustainable agricultural sector, increased competitiveness; secure markets*
• *Microbiome analysis*	*Improved soil management tools; increased plant health and yield; increased feed efficiency, reduced methane production and improved animal health; and implementation of new food processes*	*Fostering sustainable agriculture; reduced input costs for productions and development of new consumer products for food manufacturers*
• *Sustainability and social license: role and impact of genomics on agrifood*	*Engagement of different publics, assessment of societal benefits of genomic innovation;*	*Realizing socioeconomic benefits of genomics research in agrifood; guiding policy*

	data driven, evidence based support for policy and regulation in agrifood	*decisions for sustainable and efficient management in agrifood in the future*

4.2 Sector Innovation Centre for Plant Health

Plant health is an emerging area where genomics is having near term impact and is seen by Genome BC as being sufficiently ready for the development of a Sector Innovation Centre (SIC). The Federal Government is committed to establishing and maintaining a modern federal science infrastructure to develop a world-class Science Centre for Plant Health. In Budget 2017, the Government proposed to provide $80 million on a cash basis over five years, starting in 2017-18, to replace the Canadian Food Inspection Agency's (CFIA's) hundred-year-old Sidney Centre for Plant Health. CFIA's new plant health research facility with modern infrastructure will help protect the safety of Canada's agriculture sector and provide an ideal anchor for a SIC in partnership with Genome BC and other stakeholders. The SIC is envisioned to be a connected plant diagnostics network of provincial and private laboratories using common informatics resources to link with academia, industry, and other end users. New genomic technologies for pest and pathogen diagnostics and bioinformatics tools will be developed, validated, and deployed for rapid detection and result-sharing. Through engagement with key partners from industry, government, academia, and CFIA, Genome BC and other funding bodies see an opportunity to develop an integrated, evidence-based approach to maintain and distribute propagative plant material via a National Clean Plant Program to protect and support Canada's food supply, trade, environment, and economy. The governance structure for the SIC will be informed by the various partners involved and will consider the shared vision around partner needs, interests, and contributions.

4.3 Community engagement

While the cutting-edge technology opportunities and genomics applications are well known among BC researchers engaged in agrifood genomics, there is a persistent gap between this community and some managers and executives in both the public and private sectors whose responsibilities relate to broader issues of public policy, management or competitiveness. To increase the adoption of genomics-based tools and achieve high impacts in industry sooner, a coordinated approach to community engagement is required.

5. Advancing the Implementation of Genomics

To achieve these targets, Genome BC has been consulting with stakeholders in BC's agrifood sector and across Canada, as well as with international experts, to understand how genomics might 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 agrifood 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 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 BGH
- 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 Agrifood Sector Advisory Council, as at March 1, 2018

- Deborah Buszard, University of British Columbia
- Reg Ens, BC Agriculture Council
- Joan Easton, Ministry of Agriculture
- Janice Larson, Muse&Effect Consulting
- Kenna MacKenzie, Agriculture and Agri-Food Canada
- James Pratt, BC Food Processors Association
- Jane Pritchard, Ministry of Agriculture
- Ricky Yada, University of British Columbia

Appendix 2. List of Key Projects

151WIN – Grape and Wine Genomics (2009-2013)

Total Budget: $3.4M

Program: Large Scale Applied Research Program

Project Leaders: Hennie van Vuuren (UBC) and Steve Lund (UBC)

The contribution of BC wine sales to provincial agri-business has grown significantly over the past decade. In 2011, the BC wine and grape industry contributed a total of $2.01Billion of overall economic impact (made up of revenue and wages) to the BC economy. The process of producing superior wines is complex, fraught with the intricacies inherent in viticulture (grape biology), wine yeasts, and enology (winemaking), all of which are being addressed by these projects. This project involved collaborations between Canada, and the US to identify changes at the molecular and biochemical level that affect grapevine cultivation, grape processing and fermentation by yeasts. The yeast research group had good success uncovering new genes and pathways involved in wine spoilage and stress response, and resulted in the submission of one provisional patent and several research grants and contracts to further these research results. The GE3LS project also had significant collaboration with researchers in key wine producing regions around the world to study the competitiveness and success of wine clusters, which resulted in the publication of a book. This project is builds on previous two previous investments in WineGen and GrapeGen.

SOF131 – Poplar and Cereal Rust Comparative Genomics – Identification of Pathogen Determinants to Prevent and Predict Epidemics (2010-2012)

Total Budget: $372K

Program: Strategic Opportunity Fund Program

Project Leaders: Richard Hamelin (UBC) and Guus Bakkeren (AAFC)

"Rusts" are a group of fungi that attack and damage plants and trees, and cost the international agriculture and forestry sectors billions annually in lost revenue, with an estimated loss of $200M/year due to the destruction of cereal crops in Canada. This project used genomic tools to generate a catalog of genes and investigated gene expression during the pathogen-host infection process, as well as setting up international collaborations to re-sequence genomic data on source population of rusts in France, allowing the researchers to retrace the evolutionary origins of rust in North America. The Pt datasets generated have also strengthened the International collaboration with the Broad Institute and several labs at the USDA working on wheat rust diseases. The resources generated have been instrumental in funding two LSARP Genome Canada projects (TAIGA and POPCAN) and the resources generated are directly used in those projects.

225RVA – Reverse Vaccinology Approach for the Prevention of Mycobacterial Disease in Cattle (2015-ongoing)

Total Budget: $7.35M

Program: Large Scale Applied Research Program

Project Leaders: Andrew Potter (University of Saskatchewan) and Bob Hancock (UBC)

Infectious diseases continue to be a leading cause of sickness and death in livestock and are of concern to human health due to their potential to be transferred to people. Vaccination is the most cost-effective means of preventing infectious disease in animals and humans, but its application to livestock is still limited, and the lack of effective vaccines contributes to the excessive use of antibiotics in animal health. This project aims to use 'reverse vaccinology' to develop vaccines for Johne's disease and bovine tuberculosis in cattle. These diseases result in annual losses of more than $86 million and $10 million, respectively, in Canada and billions annually worldwide. The major deliverables of this project will be two new vaccines for the above diseases influencing the food and dairy industries, companion diagnostics that will differentiate vaccinated from infected animals, and a white paper to inform the public, producers, industry and government on the options and strategies for dealing with these important cattle diseases. The vaccines developed through this project will benefit dairy and beef cattle farmers, the public who utilize their products and the commercial sector, both in terms of marketable vaccines, increased food and dairy product output, and international trade. Proof of concept work for this project was developed in a previously funded Genome BC project.

227BEE – Sustaining and Securing Canada's Honey Bees Using 'Omic Tools' (2015-present)

Total Budget: $7.2M

Program: Large Scale Applied Research Program

Project Leaders: Leonard Foster (UBC) and Amro Zayed (York University)

Honey bees are a crucial part of Canadian agriculture, contributing at least $4.6 billion/y: they produce between eighty and ninety thousand tonnes of honey each year and their pollination activities directly support the production of many fruits, nuts and vegetable crops. But the health of honeybees has been declining over the past decade, with Canadian beekeepers losing more than a quarter of their colonies each winter since 2006-07. We often replace these colonies by purchasing bees and queens from offshore but we cannot rely on these sources because of the risk of importing new diseases or invasive strains of honeybees (such as the Africanized 'killer' bee). The high colony losses, coupled with the possible loss of access to replacement sources, pose a serious threat to the productivity of major Canadian agrifood industries and jeopardize our food security. Left unchecked, the production and accessibility of fruits, nuts and vegetables will decline. Our team of researchers will improve the health of Canadian honey bees by developing new genomic and proteomic tools that will enable beekeepers to rapidly and cost-effectively breed healthy, disease-resistant, productive bee colonies that are better able to survive our harsh Canadian winters. The availability of high-quality, locally bred honeybees should reduce Canada's dependence on imported queens. In parallel, we will increase the safety of bee importations by developing an accurate and cost effective assay to detect bees with Africanized genetics. Our research team will work with a large number of beekeepers across five provinces, industry technology-transfer teams, diagnostic labs and government regulators to ensure that our 'omic tools are implemented and accessible to the beekeeping industry by the end of the project. Our innovative efforts aim to help guard the safety and sustainability of the beekeeping industry, ensuring our food security and supporting billions in value to the Canadian economy. This project is builds on two previous investments in bee applied research.

UPP028 – Validation of Next Generation-based Method for Virus/Viroid Detection in Propagative Tree Fruit Material (2017-present)

Total Budget: $397K

Program: User Partnership Program

Project Leaders: Michael Rott (CFIA) Nick Ibuki (Summerland Varieties Corporation) and Travis Banks (Vineland Research Innovation Centre)

High quality tree fruit production requires plants free of harmful pests and diseases. A statistical overview of the Canadian fruit industry by Agriculture and Agri-Food Canada, estimated that tree fruits in Canada generated $240 M in revenues in 2011, with over 30% ($75M) from British Columbia, second behind Ontario at $108M. Damage caused by viruses and virus-like pathogens can be very serious. Plum pox virus (PPV) is the most economically important disease of stone fruits worldwide. Since 2000, Canada has spent $160M to eradicate PPV. The Canadian Food Inspection Agency (CFIA) Centre for Plant Health (CPH) is responsible for developing and enforcing regulations on the import of propagative plants into the country and requires that this material be free from regulated pests and pathogens. Propagative tree fruit material from unapproved sources takes three years. Though vital, the long time frames can put Canadian growers at a competitive disadvantage with respect to testing new variety imports.

The CFIA Sidney Laboratory has developed a metagenomic approach using next generation sequencing (NGS) and advanced bioinformatics to rapidly identify viruses and viroids from tree fruit samples. This will be a disruptive technology with the potential to reduce testing from years to weeks, speeding up the release process for new, high-value crops. This technology would also enable growers to effectively monitor that 2nd, 3rd and 4th generation propagation material is maintained virus-free through independent fee-for-service laboratories certified by CFIA. This is a critical step for an industry proposed national clean plant program (NCPP).

SIP001 – Functional Genomics of Terpene Variation in Medical Cannabis (2017-present)

Total Budget: $236K

Program: Sector Innovation Program

Project Leaders: Joerg Bohlmann (UBC) and Jonathan Page (UBC)

Production of medical cannabis is the fastest growing agri-biotech industry in British Columbia (BC). In addition, the Government of Canada Task Force "Report on Cannabis Legalization and Regulation" is anticipated to lead to federal legislation, under which non-medical cannabis production and distribution will transform into a regulated, multibillion-dollar industry. Much of the cannabis industry is concentrated in BC with over 20% of Canada’s licensed producers. A major issue for the industry is access to well-defined cannabis varieties with supporting scientific information on their quality traits. Such varieties will be critical for standardized cannabis production. Currently, much of the industry uses less well-defined "strains", which often have great variation in their chemical composition of small molecules that comprise the cannabis resin. In total, over 500 different small molecules contribute to cannabis resin. The majority of these small molecules are the terpenes and cannabinoids, which together define the unique pharmacological and sensory properties of different cannabis products. This project capitalizes on a timely opportunity of recent advances in cannabis genomics converging with the development of a regulated cannabis agri-biotech industry and the leading expertise of the Project Leaders. The results of this project will enable development of cannabis varieties with defined terpene profiles using breeding or genome-editing and will deliver methods, new standards and reference metabolite profiles for cannabis terpenes, which are of critical importance for testing labs and licensed producers in a regulated cannabis industry. Cannabis production with improved traits will help cement BC's developing cannabis agri-biotech industry as a global leader. The immediate users of the project's deliverables are licensed producers and testing labs. The benefits of standardized cannabis products will reach patients as the ultimate end-users. Knowledge and technology transfer and up-take will be accomplished through involvement of Anandia Laboratories Inc. as an industry partner.

DivSeek – Divseek Canada: Harnessing Genomics to Accelerate Crop Improvement in Canada (2018-present)

Total Budget: $798K

Program: Emerging Issues and Opportunities

Project Leaders: Loren Rieseberg (UBC)

Rapid population growth, a changing climate, and increasing constraints on land, water, and nutrients threaten global food security. Canada must dramatically expand agricultural production to meet increased demand and to offset predicted declines in crop yields in tropical and subtropical countries. This will require that plant breeding be accelerated in Canada, with the goal of developing high yielding, climate-adapted and “planet friendly” varieties.

Currently crop genomic data are rapidly growing in quantity but the ability of crop breeders to easily utilize the data for the benefit of developing new crop varieties is lagging. DivSeek is an international initiative that aims to accelerate plant breeding by leveraging the genetic diversity in the world’s live collections and seed banks (“genebanks”). To be effective, a unified, coordinated and cohesive database is necessary to allow breeders and farmers to access this important information.

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