Ontario Genomics

CELLULAR AGRICULTURE

CANADA'S $12.5 BILLION OPPORTUNITY IN FOOD INNOVATION

REPORT

November 2021

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Cellular Agriculture – Canada's $12.5 Billion Opportunity in Food Innovation - Executive Summary

Driven by an accelerating climate crisis, evolving consumer preferences, worsening global food insecurity, and the need to feed a growing global population, cellular agriculture presents an alternative and compelling route to produce proteins, ingredients and other food products[a] thereby augmenting global food systems. In recent years, the cellular agriculture industry has been exploding, with over US$9.7 billion in global investments and more than one hundred active companies worldwide. This is an industry that is flourishing with opportunities for current and new food producers across diverse and multi-sectoral public and private stakeholder groups.

Cellular agriculture encompasses several innovative approaches that use cell cultures, tissue engineering, or precision fermentation to make food products and other materials. Cellular agriculture is underpinned by the platform technology of engineering (synthetic) biology, a convergence of advanced biological, engineering and computational disciplines to create products for numerous sectors in new and sustainable ways.

The first-of-its-kind in Canada, the current report, *Cellular Agriculture – Canada's $12.5 Billion Opportunity in Food Innovation* is based on extensive stakeholder engagement and builds on the landmark whitepaper, *Engineering Biology – a platform technology to fuel multi-sector economic recovery and modernize biomanufacturing in Canada*. Released in November 2020, by Ontario Genomics and the Canadian National Engineering Biology Steering Committee, this whitepaper highlighted the opportunity to use engineering biology as a platform technology for sustainable and innovative economic recovery and growth in three vertical pillars: Food Security, Low-Carbon Manufacturing, and Advanced Engineering Health Technologies.

The analysis presented here illustrates that the Canadian cellular agriculture landscape is rapidly evolving and shows tremendous promise to develop alongside and augment Canada's conventional agriculture and food industries, with Canadian start-ups already taking advantage of growing opportunities along the supply chain. As the fifth largest exporter of agricultural and agri-food products in the world and aligning with the ambitious vision of the Economic Strategy Table on Agri-Food's vision for Canada to become the favoured protein provider globally, Canada has unique advantages to drive leadership in cellular agriculture. This includes an extensive food and beverage industry, free-trade agreements covering 60% of global GDP, readily available feedstock, and world-class expertise across required disciplines. The report's economic analysis, by Dr. Michael von Massow, indicates that there is an enormous opportunity for Canada to capitalize on cellular agriculture. This includes the ability to

[a] In addition to food ingredients (such as proteins, enzymes, flavour molecules, vitamins, pigments and fats) that can be incorporated with existing products to create value-added hybrid goods, fermented products include dairy, eggs, chocolate, honey, while cellular/cultivated products comprise red meat, poultry, seafood, foie gras and pet food. Non-food cellular agriculture products cover textiles such as leather, wool, silk and cotton.)

diversify and create new product categories for domestic and international markets, supporting company creation and Canadian Intellectual Property generation, as well as an opportunity to address food security concerns in Canada and globally. Optimistic scenarios suggest a $7.5 billion a year industry and up to 86,000 jobs created by 2030, and longer-term Canadian revenues as high as $12.5 billion per year with the creation of up to 142,000 jobs; this is achievable and aligned with Canada's current share of the global market.

Funded by Ontario Genomics and Agriculture and Agri-Food Canada, Ontario Genomics, in partnership with the Food and Agriculture Institute at the University of the Fraser Valley, conducted a series of stakeholder consultations to explore critical considerations for Canada's emerging cellular agriculture industry. Based on these consultations and a review of literature and publicly available information, this report outlines inter-connected actionable opportunities for Canada to capitalize on this rapidly expanding and high-potential global market expected to approach US$100 billion in the next decade. To achieve success, Canada must:

1. *Develop a National Vision and Strategy for a Canadian Cellular Agriculture Industry in the Near Term.* This is foundational to enable a growing domestic ecosystem and fully realize the benefits presented by this industry. An outcomes-driven national vision and strategy should be developed collaboratively, be inclusive of stakeholder requirements and include a clear plan for implementation in the short-, medium- and long-term.
2. *Establish a Clear and Transparent Regulatory Framework for Cellular Agriculture Products in Canada.* Canada is encouraged to proactively develop an agile, iterative, and innovative regulatory framework by building on existing processes to support the evaluation and approval of cellular agriculture products in a timely manner, in alignment with Canada's current rigorous regulatory process and excellent food safety standards.
3. *Provide Supporting Mechanisms for Research and Commercial Development.* Incentivization, through public and private investment and partnerships, and outcomes-driven networks, is critical for a thriving domestic cellular agriculture industry, with infrastructure support for research and development, training, company creation, scale-up and growth, leading to made-in-Canada product commercialization.

Introduction

Agriculture and food systems are changing, driven by increasing ecological concerns, an accelerating climate crisis, worsening global food insecurity, and the need to feed an expected 9.7 billion people by 2050[1] and 11 billion by 2100.[2] Consumer preferences are also changing, with an increased demand for animal proteins amongst the emerging middle classes in developing countries[3] and a trend toward more Westernized diets in much of Asia.[4] While varying by demographic,[5, 6, 7] in wealthy countries, such as Canada, there is increasing demand for plant-based proteins and alternatives to animal-based diets.[8, 9, 10] Environmental, ethical, and health considerations are driving a concurrent rise in flexitarianism, veganism and vegetarianism.[11, 12] Meanwhile, 1 in 4 people are food insecure globally,[13] and 1 in 8 Canadians (4.4 million) reported food insecurity in 2017-18, with significantly higher rates among Black and Indigenous peoples.[14] Food insecurity soared with disruptions to supply chains due to the COVID-19 pandemic and may worsen based on current models of the impact of climate change.[15]

Through strategic consultations, a review of literature, landscape analysis, and an economic analysis of the opportunity and benefits to Canada (see Appendices A and B), this report, *Cellular Agriculture – Canada's $12.5 Billion Opportunity in Food Innovation*, explores the role of and opportunities for cellular agriculture in creating "made-in-Canada" solutions for a sustainable and resilient food supply chain, while capturing market share in changing global economies. This report builds on the landmark whitepaper, *Engineering Biology – a platform technology to fuel multi-sector economic recovery and modernize biomanufacturing in Canada*. Released in November 2020, by Ontario Genomics and the Canadian National Engineering Biology Steering Committee, this whitepaper highlighted the opportunity to use engineering (synthetic) biology as a platform technology for sustainable and innovative economic recovery and growth in three vertical pillars: Food Security, Low-Carbon Manufacturing, and Advanced Engineering Health Technologies.

Funded by Ontario Genomics and Agriculture and Agri-Food Canada (AAFC), Ontario Genomics, in partnership with the Food and Agriculture Institute (FAI) at the University of the Fraser Valley, conducted consultations (interviews and focus groups) with a cross-section of over sixty-five Canadian and international leaders and experts in relevant fields across industry, academia, investors, funders, policymakers, government, and not-for-profit stakeholders. Outcomes from these consultations, in conjunction with a thorough review of literature, reports, and other sources, are consolidated to identify key priorities and actionable opportunities in cellular agriculture for Canada to capitalize on this significant and rapidly evolving global trend. Additionally, Dr. Michael von Massow, University of Guelph, carried out an economic analysis to contextualize the scale of the economic opportunity for cellular agriculture ingredients and products across the food system. This analysis provides scope for the potential size of Canada's cellular agriculture market in terms of demand, production, exports and employment opportunities. Outcomes from this report will inform AAFC of the opportunities and challenges related to the emergence of innovative agricultural technologies, as well as inform the Food Security Pillar of the National Engineering Biology Strategic Framework led by Ontario Genomics and the Canadian National Engineering Biology Steering Committee.

Precision Fermentation In Cellular Agriculture: cells, such as yeast, can be grown in microbrewery-like tanks to produce large quantities of the desired product that they would not normally be able to produce (e.g. egg white protein), without the use of animals.

Tissue Engineering In Cellular Agriculture: cells from livestock, seafood or fish are grown outside the body to produce muscle tissue, fat or other tissue types that can be used as ground meat product. To produce a cut of meat, such as a steak, chicken breast or fish fillet, the cells are grown on a "scaffold", to produce a 3D structure. This is much more complex than the production of ground meat product and is an area of intense research.

Background

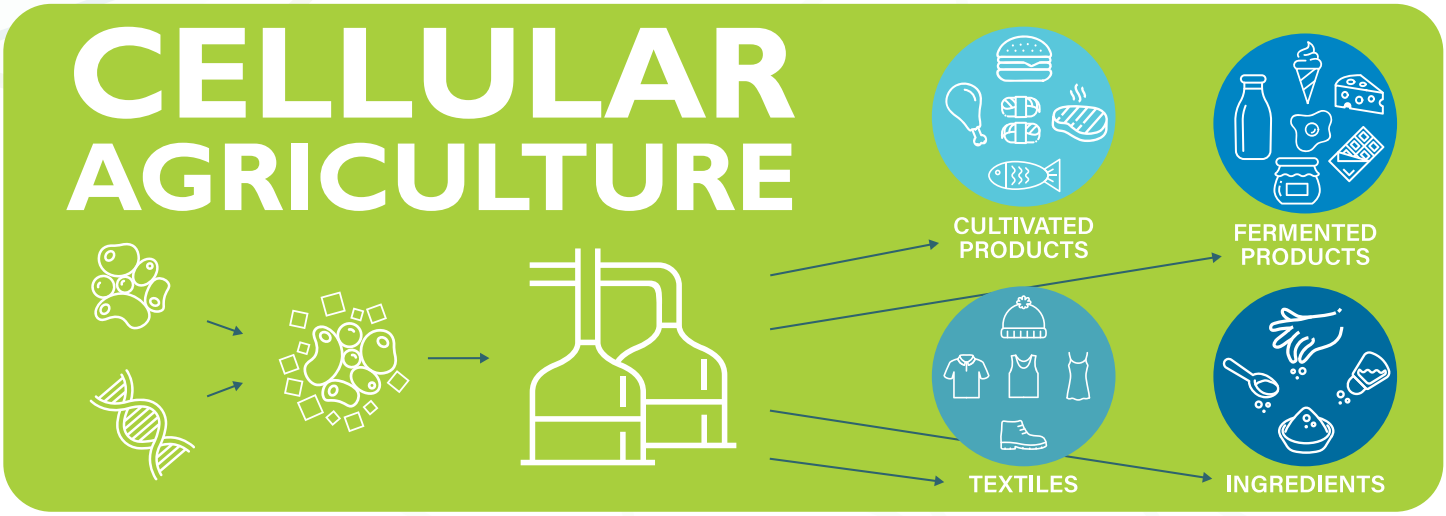
Global meat and protein demand is expected to increase by 76% by 2050.[3] Although conventional agriculture will continue to play an important role, new and alternative protein production methods are essential to sustainably meet these growing protein requirements under current and evolving conditions, and minimize the environmental impact associated with further conventional agricultural expansion. As we enter a "fourth agricultural revolution,"[16] food systems will increasingly rely on new, more efficient production methods and technologies to strengthen food systems while enhancing resilience protect against disruption in the supply chain. *Cellular agriculture* is the use of cell cultures, tissue engineering, or precision fermentation-based techniques to create products commonly made through conventional agriculture. As a new food production system, it presents an alternative and compelling route to produce proteins, ingredients, and other food products. In addition to food ingredients (such as proteins, enzymes, flavour molecules, vitamins, pigments and fats) that can be incorporated with existing products to create value-added hybrid goods, *fermented products* include dairy, eggs, chocolate, honey, while *cellular/cultivated*[a] *products* comprise red meat, poultry, seafood, foie gras and pet food. Non-food cellular agriculture products cover textiles such as leather, wool, silk and cotton. The key challenge and goal for cellular agriculture, particularly in the food sector, is to demonstrate parity - when the price, taste and texture of new and alternative proteins closely match those of animal protein products.

[a] As a new field, the terminology has not yet been broadly agreed upon and there are varying names used to describe the same types of products, e.g., cultivated meat (including seafood), cellular meat, cell-cultured meat, animal cell based meat, and others. For the purposes of this report, we will use "cultivated" to refer to these types of products.

Cellular agriculture has roots in engineering biology, a cross-sectoral platform technology built on the convergence of advanced methodologies and disciplines, enabling biomanufacturing of numerous products, including food and textiles.

Cellular agriculture is primarily underpinned by engineering biology (see Box 1), a platform technology built on the convergence of advanced biological and engineering disciplines coupled with sophisticated artificial intelligence (AI) and computational methodologies as well as nanotechnologies, resulting in an entirely new way of creating all kinds of products, including food. These technologies have long-established roots and were originally pioneered to create a new pathway for insulin synthesis, which became available in 1982 as a much more reliable source of insulin.[17] This advance was foundational to modern genetic engineering, and ongoing advancements in the medical field can be most recently observed in the development of mRNA COVID-19 vaccines.[18]

Food ingredients produced using this technology are also already on the market, including rennet for cheesemaking, which has been created using genetically engineered yeasts and bacteria since the early 1990s.[19] Demonstrating the multi-generational development of this technology, as well as highlighting the earlier market opportunities for precision fermentation-based food ingredients, in 2016, *Impossible Foods* successfully marketed their plant-based burger containing engineered soy leghemoglobin, an analogue of animal-derived heme that provides the burger's meaty taste and texture. This burger is widely available, including in Canada and the United States (US).[20] Cell-cultivated products evolved more recently and are still undergoing development, from the first-ever production of goldfish muscle tissue in 2002,[21] to a prototype beef-based burger unveiled in London in August 2013. While the initial €250,000 (~US$330,000) cost of the burger was prohibitive, the industry has since focused on decreasing the cost while increasing crucial characteristics such as taste and texture,[22] with some predictions for expected parity with conventional meat around 2032.[23] Several other cellular agriculture companies are focusing on textiles using precision fermentation, including *Spiber's* silk, with recently announced plans for industrial scale production.[24] These examples demonstrate the broad applicability of the engineering biology platform, which can be applied to solve challenges and create opportunities across multiple sectors and business verticals.[25]



The recently released *Sixth Assessment Report* from the Intergovernmental Panel on Climate Change projects that the severity and frequency of agricultural drought will increase in many regions across the globe,[26] exacerbating worldwide food production challenges. Temperature increases are associated with reductions in crop yields,[27] while unpredictable weather patterns, extreme temperature spikes, and pests and diseases are causing more frequent crop losses. The climate crisis will

continue to worsen food insecurity globally,[28] creating a pressing need to develop novel technologies and food production methods that can increase yields, strengthen food systems, and provide resiliency to climate change and other disruptions. At the same time, globally, the agricultural sector is the largest driver of land-use change,[29] with nearly 40% of the earth's land surface currently used for either crop production or grazing.[30] Current food production systems are responsible for between 21% and 37% of annual greenhouse gas emissions (GHG), including approximately half of all anthropogenic methane emissions and three-quarters of nitrogen emissions.[31, 32] Globally, Canada ranks in 20th place in the environmental performance index (EPI) and in 168th place for per capita GHG emissions out of 180 countries examined.[33] However, Canada is a global leader in reducing the environmental impact of its livestock industry, and the agricultural GHG emissions per mass of Canadian beef, representing the most considerable livestock GHG emitter, is among the lowest globally.[34] In addition, due to concerted efforts and widespread implementation of sustainable practices, Canada's agricultural land is a net carbon sink.[35] Notably, over the past 22 years, Canadian agricultural output has doubled while the impact on emissions has been negligible.[36]

Despite technological and environmental advances, conventional food production in Canada and globally has limitations, and new food production methods will be necessary to sustainably meet increasing demand. Furthermore, given Canada's overall ranking on GHG emissions on a per capita basis and the country's commitment to net-zero emissions by 2050, novel food production methods present a promising means of reducing emissions and moving towards our sustainability goals. Cellular agriculture is potentially environmentally beneficial when compared with conventional production methods. For example, in 2021, *Perfect Day* commissioned a comparative life cycle assessment (LCA)[b] conforming to ISO standards 14040 and 14044, to compare GHG emissions, energy demand and blue water (i.e., fresh surface and groundwater) consumption of *Perfect Day's* animal-free dairy protein production with conventional dairy protein production. The results indicated that *Perfect Day's* production method produced 91% to 97% less GHG emissions, required 29% to 60% less energy, and used 96% to 99% less blue water.[37, 38] While these results are promising, much broader LCAs and techno-economic analyses (TEAs)[c] on a product-by-product basis are critical for understanding and improving cellular agriculture's contribution to environmental and economic sustainability in Canada and globally.

SPOTLIGHT

Production of *Perfect Day's* animal-free dairy protein reduces GHG emissions by up to 97%, and uses up to 60% less energy and up to 99% less blue water (suitable for human use) than conventional dairy protein production.

New food production technologies offer significant opportunities for economic growth and job creation. The global meat, dairy and ingredients markets, worth a combined US$1.6 trillion,[39, 40, 41] presents significant potential along the food supply chain for new products in the cellular agriculture and alternative proteins market. McKinsey Global Institute's *Bio-Revolution Report*[42] describes the coalescence of multiple biological and computational disciplines leading to rapidly advancing, disruptive technologies, with innovation in agriculture, aquaculture, and food estimated to be worth an annual economic value of US$800 billion-$1.2 trillion. New proteins, such as cultured meat, plant-based meat, and synthetic proteins, have an estimated value of US$40-120 billion. More recently, the Boston Consulting Group and Blue Horizon Corporation *Food for Thought Report* estimated that the alternative protein market (plant, microorganism and animal cell-based) is set to reach at least US$290 billion by 2035 with the profits

[b] Life cycle assessment (LCA) - quantitative assessment of a product's environmental impacts throughout the life cycle, from initial material extraction to end-of-use

[c] Techno-economic analysis (TEA) - assessment of the technical and economic viability of a product, taking both costs and anticipated revenues into account

distributed throughout the value chain. Critical points contributing to that model include increasing public concern for climate change, and investors' incorporation of environmental, social, and corporate governance (ESG) criteria into their investment strategies[23] in alignment with the United Nation's Sustainable Development Goals.[43] These are expected to generate enough consumer demand and investor interest to unlock parity (taste, texture, price) of plant-based, fermentation-based, and animal-cell based alternative proteins.[23]

In addition to economic and environmental opportunities, the ability to finely control the composition of cellular agriculture products provides products with comparable taste to conventional foods while reducing or eliminating components that are harmful to human health (hypo- or non-allergenic; less trans-fats and cholesterol).[44] It could also avoid artificial contaminants such as antibiotics in meat, or mercury and microplastics in seafood.[45] When scaled up, the tunability of cellular agriculture products opens valuable opportunities for producing healthy, nutritious, safe, and appealing protein products worldwide.

Canada has a tremendous opportunity to support and develop a cellular agriculture sector. Economic analysis in this report indicates that a conservative revenue estimate for 2030 could represent $1.5 billion and between 3,600 and 17,000 jobs, while the optimistic scenario for 2030 suggests a $7.5 billion a year industry and could represent from 18,000 to more than 86,000 jobs. Longer-term optimistic estimates suggest potential Canadian revenues as high as $12.5 billion, creating between 30,000, and 142,000 jobs (see Economic Analysis). Canada is a global leader in developing and improving agricultural technologies and is the fifth largest exporter of agricultural and agri-food products in the world.[46] Canada also has a global reputation as a supplier of safe and high-quality products. Furthermore, the Economic Strategy Table on Agri-Food set an ambitious goal recommending that: *"Canada will be one of the top five competitors in the agri-food sector, ...[an] innovator in value-added products to feed the dynamic global consumer... and stand out as the world's favoured protein provider."*[47] Federally funded superclusters are already contributing to this goal: Protein Industries Canada (PIC) focuses on applying plant genomics and novel processing technologies to enhance yield and value of plant-derived proteins from field to fork. Canada's Oceans Supercluster accelerates the development and commercialization of globally relevant ocean solutions, including sustainable proteins and oils. However, for Canada to become a global leader in culturally relevant, socially responsible, and environmentally sustainable agri-food production, cellular agriculture must be part of the strategy moving forward. Cellular agriculture presents an opportunity to diversify and create new product categories and become an economically viable and essential industry in Canada that produces goods for domestic and international markets.

Canada is a world leader and has an advantage over many countries in producing the agricultural precursors essential to the cellular agriculture production chain (e.g., feedstocks, starches). Additionally, Canada has the necessary technological expertise (see Box 1) and Ontario has the third-largest food and beverage manufacturing sector in North America,[48] with additional strong capacity in other provinces.[49] Cellular agriculture presents a critical economic opportunity for food and beverage companies, start-ups, and others along the value chain (business-to-business companies (B2B) and business-to-consumer companies (B2C)) to satisfy the evolving needs of the modern-day consumer and increase food production for Canada and the world under current and evolving constraints.

Box 1. Engineering Biology, Genomics, and Converging Technologies

Cellular agriculture is broadly founded on the knowledge, tools and methodologies from engineering biology. Engineering biology is a cross-sectoral platform technology built on the convergence of 'omics (e.g., genomics, proteomics, metabolomics), molecular biosciences, engineering disciplines, computing, artificial intelligence, miniaturization, robotics and automation, all of which are fields where Canada has extensive expertise. The application of engineering principles to biological systems has led to extensive and rapid advancements in our ability to read, write and edit DNA, which in turn has enabled innovative re-programming or de-novo design of biological systems to create biological "factories" capable of producing up to 60% of global economic inputs.[B1]

For researchers and start-ups working in the cellular agriculture space, engineering biology has rapidly advanced the sector. This includes the development of precision fermentation, whereby microorganisms are programmed to produce specific proteins. The cells or "biological chassis" for precision fermentation include bacteria, fungi and yeasts, algae, insect and plant cells.[B2, B3] Engineering biology methodologies and genomic technologies, more broadly, can also be applied to cultivated meats and seafood, for example, to improve growth parameters or product composition, cell source, growth media, food safety, scaffolding, and more.

The multidisciplinary nature of cellular agriculture, requiring cross-sectoral knowledge, sharing and collaboration, will contribute to and benefit from technology solutions and know-how from other sectors in which Canada has notable expertise. Examples include digital and computational technologies critical to the design-build-test-learn process inherent to engineering biology,[B4] 3D printing, with opportunities such as bioprinting techniques for manufacturing cultured meat tissues (e.g., Redefine Meat's 3D Alt-Meat Printers),[B5, B6] from the medical sciences, for example innovations in tissue scaffolding (e.g., Tijore and colleagues;[B7] Whiteboard Foods/Spiderwort), stem cell biology, with Canada's global leadership in this field supported by the federal government, for example through the Stem Cell Network, with past investments totalling $118 million and an additional $45 million announced in the 2021 budget (https://stemcellnetwork.ca/), and industrial biotechnology, a focus area of the National Research Council and highlighted in Canada's 2021 budget as a key sector to drive post-pandemic economic recovery.[B8, B9]

As Canada develops a cellular agriculture industry, it will be critical to leverage the extensive expertise that we have here and ensure communication across industries using established networks such as through the National Engineering Biology Steering Committee and Can-DESyNe.

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Cellular Agriculture Worldwide

The sector has been exploding globally with ever evolving and diverse applications and currently over one hundred active cellular agriculture companies worldwide.

> *"The most egg-citing developments will be the advent of Food 2.0. The age of molecular food is just beginning to unfold. We're just beginning to harness the potential of biotech to look at food at the molecular level––at the level of the individual protein rather than the whole product."*
>
> Arturo Elizondo, CEO, The EVERY Company
>
> From: Voices of Biotech Leaders

Cellular agriculture companies are working on a wide range of precision fermentation products such as:

- Dairy (*Perfect Day, TurtleTree*)
- Eggs (*The EVERY Company - previously Clara Foods*)
- Gelatin (*Geltor*)
- Myoglobin (*Motif FoodWorks*)
- Honey (*MeliBio, Inc.*)

Or cultivated products such as:

- Beef (*Mosa Meat, Aleph Farms*)
- Chicken (*JUST, SuperMeat, Upside Foods - previously Memphis Meats*)
- Foie gras (*Gourmey*)
- Seafood (*Wildtype, Finless Foods, BlueNalu, Shiok*)

From IndieBio's recent graduating cohort, *California Cultured* produces chocolate from plant stem cells, culturing specific high-value flavanols and functional compounds that enrich the flavour and nutritional profile of chocolate.[50]

Other emerging applications are in the production of:

- Leather (*Modern Meadow*)
- Silk (*Bolt Threads, Spiber*)
- Cotton (*GALY*)

These early companies tend to be "fully verticalized," meaning that they take care of every step in the pipeline themselves, from initial cell culture to bringing the product to market. The next wave of entrants into the industry will also include B2B companies that specialize and excel in one part of the supply chain, e.g., cell media and growth factors or fermentation feedstock, scaffolding and matrices, and key ingredients. This presents exciting opportunities for technology providers, new start-ups and others along the supply chain. New companies, products and investments are emerging at an unprecedented rate, presenting unequivocal economic and social opportunities worldwide.

SPOTLIGHT

There are **over 100 cellular agriculture companies** worldwide (and growing!), working on a range of products such as dairy, eggs, chocolate, chicken, beef and seafood, among others like silk, leather, wool and cotton.

SPOTLIGHT

A number of cellular agriculture products are already on the market, including the ***Impossible Burger™***, containing heme made by precision fermentation; ice cream containing ***Perfect Day's*** dairy protein; ***The EVERY Company's*** egg white-equivalent protein; and, in Singapore, ***Eat Just*** chicken bites can be found in restaurants on a small scale.

Today, some of these products are not just in the discovery or early development phases. The *Impossible Burger*™ has been widely available for years; *Perfect Day's* ice cream, made with fermentation-derived milk proteins, is available at five thousand stores across the US and in Japan, and cream cheese products are set to launch imminently,[51, 52] and *The EVERY Company* launched its egg white-equivalent protein in October 2021.[53] Cellular meat products are currently available at a small scale in restaurants; *Eat Just* chicken bites in Singapore and *SuperMeat's* chicken burgers and rice rolls in Israel.[54]

Many more products are getting closer to market, with precision fermentation products expected to emerge sooner than cellular products due to the advanced nature of the technology and differences between the product types. To accelerate production scale-up, companies are forming strategic partnerships with large food Corporates, including *Perfect Day* (US, cow-free dairy) partnering with *Archer Daniels Midland* (ADM);[55] *The EVERY Company* (US, animal-free egg protein) with *ZX Ventures*; *BlueNalu* (US, cellular aquaculture) with *Griffith Foods*;[56] and *Geltor* with Switzerland-based *Lonza Specialty Ingredients*.[57]

Cultivated meat and seafood companies face significant technical and financial challenges to scale up and reach price parity.[58] Nevertheless, the industry is pushing forward, with recent announcements of operational plants. This includes *Wildtype Foods* (US, cell-cultured seafood), *Upside Foods* (US, chicken) and *Future Meat Technologies* (Israel, cell-cultured chicken and beef), while Aleph Farms (Israel) has pilot plant construction underway. Moving towards price parity, Future Meat Technologies produces an impressive 500 kg of meat a day, for $4 per 100 g of cultivated chicken breast.[59] *Unicorn Biotechnologies* (UK) plans to build bioreactors specifically for cultivated meat, while *Culture Biosciences* builds and operates bioreactors with custom hardware and software, to meet the demand for large-scale biomanufacturing across sectors, including companies that are manufacturing food, therapeutics, and other bioproducts.[60]

SPOTLIGHT

Boston Consulting Group and Blue Horizon predict products produced by **precision fermentation** will reach price parity by 2025, and **cultivated meat and seafood** by 2032. With the right support, these products could capture **22% of the market** by 2035.

As these examples demonstrate, cellular agriculture is becoming firmly established as a food and materials production system, with the range of products already expanding and likely to be more widely available within years rather than decades. Although cellular agriculture products may initially be high-cost luxury items, as these companies grow and scale their production, they will become more widely available, as was the case for the *Impossible Burger*™.[61] BCG and Blue Horizon's Report predicts that precision fermentation products will reach parity by 2025 and cultivated meat and seafood products by 2032, allowing the capture of 11% of the global protein market

HOT OFF THE PRESS

Upside Foods opened their EPIC facility (Engineering, Production, and Innovation Center) in California on November 4, 2021. According to the company press release, this is the **most advanced cultivated meat production facility in the world**, and will be able to produce 50,000 lb of meat annually.

by 2035. They also predict the industry could achieve greater momentum with more significant public or private investment and regulatory support, which combined could boost consumption to 22% by 2035.[23] Consumer buy-in is a key success factor for this new sector's success,[62] and some companies are making cultivated foods more accessible and consumer-facing with tasting rooms and educational centres being developed by *Wildtype Foods*, *Upside Foods*, and *Future Meat Technologies*.

Currently, the industry is concentrated in a few key geographic areas, including California's Bay Area, Singapore, Israel, and the Netherlands, with rapidly expanding interest in other countries. Australia recently released *A National Synthetic Biology Roadmap*, focusing on harnessing synthetic biology as a multi-sector tool to drive commercial and economic opportunities and has cellular agriculture high on their identified priorities.[63] For the most part, countries leading in cellular agriculture have either a culture of innovation or geopolitical drivers and have been advancing the industry through various incentivization mechanisms. Between 2008 and 2014, the US government invested approximately $820 million in engineering biology, the platform technology backbone of cellular agriculture.[64, 65] As a result, the US now has a significant lead in the number of cellular agriculture companies and well-funded start-ups, as well as the most private sector investment in this sector.[66] The US Department of Agriculture (USDA) recently made a $10 million, 5-year investment into a new National Institute for Cellular Agriculture at Tufts University, to focus on all aspects of cultivated meat production - technological, economic and societal.[67, 68] With 4.95% of gross domestic product (GDP) spent on research and development (R&D), the world leader in public investment, Israel has become the "Start-up Nation" and out of more than one hundred alternative protein companies active in the space in Israel, fifteen of them are cultivated product and fermentation-based agriculture companies.[69] Singapore was the first country to grant regulatory approval to cultured meat, with *Eat Just* cultured chicken as an ingredient in chicken bites.[70] This was driven by Singapore's "30 by 30" strategic objective to increase the country's food security and resiliency by producing 30% of the country's nutritional demand by 2030.[71]

Many countries have invested heavily in entrepreneurship and early-stage companies through hubs, accelerators and incubator programs. In Europe, Mylkubator, started by Pascual Innoventures, the innovation arm of Spanish dairy company Pascual, is focused on cellular agriculture start-ups and entrepreneurs with innovative technologies in the dairy space. In Israel, The Kitchen is investing in commercializing cutting-edge technology start-ups across the global food chain, while Fresh Start, incentivized by the Israel Innovation Authority, partnered with Finistere Ventures, food manufacturers and others to establish a new food tech incubator. In the US, sector agnostic Indie Bio, Petri-Dish and Y-Combinator support early-stage engineering biology and technology companies. Singapore has various food-focused accelerators and hubs, including the agri-food technology accelerator GROW and Bright Science & Technology Innovation Hub, an innovation platform partnering with start-ups to promote equitable access to healthy food and nutrition. The Singaporean government has been gathering a dynamic array of financing firms including a partnership between the Singaporean sovereign fund/investment company Temasek and A*STAR (Agency for Science, Technology and Research) to support cellular agriculture research.[72]

In addition, not-for-profits are active in the space around the world. Examples include The Good Food Institute (US), working internationally to accelerate alternative protein innovation; New Harvest (US, Canada), a research-focused international organization,

Upside Chicken and ***MeliBio, Inc.*** honey were highlighted in TIME magazine's 100 **best inventions of 2021**.

which originated in the US and now has a Canadian branch; The Protein Directory (Denmark), which helps to connect alternative protein companies globally; Cellular Agriculture Australia, one of the most recent non-profits that is gaining momentum in the space; Canadian-based CellAgri, a news and insights platform that explores the future of food around the globe, while also offering an online course on the basics around cellular agriculture.

Furthermore, there are a growing number of courses on cellular agriculture being offered globally for interested students, including:

- The Cellular Agriculture Course at Tufts University, a comprehensive overview of the processes involved in the production of in vitro meat – from primary cow cell isolations to the generation of 3D meat tissue constructs via tissue engineering techniques.
- Cell Ag @MIT, an introduction to cellular agriculture, including bioengineering, business, and food science components.
- FoodBioSystems DTP at the University of Surrey, UK, brings together six university partners focusing on the digital design and scale-up of bioprocesses for cultured meat production.
- Singapore's Nanyang Technological University (NTU) has launched the first alternative-protein university course in Asia-Pacific – Future Foods.
- The International Genetically Engineered Machine (iGEM) Foundation, an independent, non-profit organization dedicated to advancing synthetic biology, hosts the annual iGEM event that allows students to push the boundaries of synthetic biology by tackling global challenges, and that include applications in cellular agriculture.

Cellular Agriculture in Canada

Cellular agriculture is poised to become a lucrative industry[23, 42, 73] with opportunities for diverse cross-sectoral stakeholder groups, including industry, start-ups, governments, universities and colleges, and not-for-profit organizations. As cellular agriculture grows, research and innovation opportunities are plentiful in new product discovery, technique optimization, consumer acceptance, LCAs[b] and TEAs.[c] Though scaling these technologies remains a bottleneck, more so for cultivated than fermented products, countries that invest in this industry early are becoming the global leaders in the cellular agriculture sector, benefiting from a share of international investments, Intellectual Property (IP) generation, commercialization of new products, new company creation, and product market share.

The Canadian cellular agriculture landscape is rapidly evolving and shows tremendous promise. Canadian start-ups are already taking advantage of the growing B2B and B2C opportunities, using precision fermentation and cultivated technologies to produce a wide variety of products.

FUTURE FIELDS	Future Fields, Edmonton, AB, making growth factors for the cellular agriculture market.	NOBLEGEN	Noblegen, Peterborough, ON, building ingredients and meat/dairy/egg products.
Because, Animals.	Canadian-founded Because Animals focusing on integrating cultivated ingredients into pet foods for dogs and cats.	WHITEBOARD FOODS™	Whiteboard Food (Spiderwort), Ottawa, ON, focusing on scaffolding for plant-based meat, cultivated meat or alternative proteins.
BIOFECT INNOVATIONS	Biofect Innovations, Toronto, ON, designing microorganisms and using fermentation to create valuable animal ingredient products.	ardra	Ardra, Toronto, ON, using precision fermentation to sustainability create ingredients such as flavours and fragrances.
CELL AG TECH	CELL AG TECH, Toronto, ON, focusing on seafood and a recent semi-finalist in XPRIZE Feed the Next Billion.	CARÔMEATS	Caro Meats, Hamilton, ON, making cultivated meat using bioengineering techniques.
Another Fish	Another Fish, Montreal, QC aiming to produce a whitefish fillet and another semi-finalist in XPRIZE Feed the Next Billion.	LIVEN	Liven Proteins (ingredients) and New School Foods (plant-based seafood), Toronto, ON, are working together to create new food products.
MARA	Mara Renewables, Dartmouth, NS, creating omega-3 fatty acids from algae for human nutrition and related industries.	Appleton Meats	Appleton Meats, Vancouver, BC, working on a range of cultivated meat products, including beef and mouse meat for cats.
BetterMilk	Better Milk, Montreal, QC, intending to make cow milk with mammary cells.		

[b] Life cycle assessment (LCA) - quantitative assessment of a product's environmental impacts throughout the life cycle, from initial material extraction to end-of-use

[c] Techno-economic analysis (TEA) - assessment of the technical and economic viability of a product, taking both costs and anticipated revenues into account

Nigiri sushi made with CELL AG TECH's cell cultured snapper and plant-based ingredients.

As demonstrated by incentivization models from leading countries, the development and coordination of agri-tech incubator and accelerator capacity across Canada are vital to the success of the domestic cellular agriculture industry. While there are currently no accelerators or incubators dedicated exclusively to cellular agriculture in Canada, some examples of those that support this budding industry include:

- Velocity (Waterloo), focused on early-stage, pre-seed technology start-ups.
- The Grove (London), an agri-business hub that has partnered with Forest City SynBio to build a synthetic biology start-up accelerator.
- District 3 (Montreal), working with start-ups that harness emerging technology, including its Bio Stream focused on biomanufacturing.
- The Saskatchewan Food Industry Development Centre, providing services and support to food processors and start-ups, including those focused on cellular agriculture (Saskatoon).
- Creative Destruction Lab (CDL) is a non-profit organization that delivers an objectives-based program for massively scalable, seed-stage science and technology companies, with many streams and locations, including the CDL-Rockies' Ag stream open to food technology innovation, including cellular agriculture.

Canada currently has several not-for-profit organizations that focus on cellular agriculture research, innovation, and public education to help drive momentum in Canada, including:

- Cellular Agriculture Canada was founded in 2019, working nationwide to encourage the development of Canadian cellular agricultural industries.
- New Harvest is a research-focused international organization with a Canadian branch.
- Founded in 2000, Ontario Genomics is a not-for-profit organization that leads the application of genomics-based solutions across key sectors of the economy to drive economic growth, improved quality of life, and global leadership for Ontario, and is part of the Canadian Genomics Enterprise.
- The Global Institute for Food Security operates as a public-private partnership based at the University of Saskatchewan to support a closely aligned research platform that uses engineering biology to enhance food systems.

HOT OFF THE PRESS

California Cultured **raised $4 million** in seed funding for their cell-cultured chocolate.

Investments are Significant and Growing

Significant and continually evolving investments have been made in the rapidly emerging cellular agriculture industry, with 2020-21 being a particularly lucrative year for the sector. Most of the investment has been through venture capital, institutional investors, pension funds, large corporate food players and influential investors culminating in over US$9.7 billion in investment in cellular agriculture globally and growing over the last several years. Large food corporates are expanding their footprint into new and alternative proteins, including cellular agriculture. Examples include:

- *Cargill's* investment strategy in all forms of protein, including cultivated meat companies such as US-based *Upside Foods* (formerly *Memphis Meats*) and *Aleph Farms* in Israel.[74]
- *Tyson Foods* is also investing widely across various alternative proteins, including in *Upside Foods*.[75]
- *Maple Leaf Foods* has invested in alternative proteins, including plant-based[76] and insects.[77]
- *Nestlé* has partnered with *Future Meat Technologies*[78] on cultivated meat.
- Many others are working in the cell-based infant milk space, including the Bill Gates-backed *Biomilq* and Singapore-based *TurtleTree Labs*,[79] which has recently expanded to a 24,000 sq ft precision-fermentation facility in California.[80]

These investments represent a rapid scaling up of funding that will shorten the runway to market for many of these cellular agriculture companies and demonstrate the growing momentum behind various cellular agriculture-derived products. In addition to being a good economic opportunity, cellular agriculture can also help fulfill ESG requirements as demonstrated by recent investments by leading pension funds, including:

- Canadian Pension Plan Investment Board (CPPIB), Thematic Investing group's Climate Change Opportunities strategy investing into Perfect Day's Series C and recent Series D raises[81, 82] and
- Ontario Teachers' Pension Plan Board's investment into Motif FoodWorks.[83]

Although most of these investments have occurred outside of Canada to date, it is promising to see a willing cohort of Canadian-based (Table 1) and international investors poised and actively investing.

SPOTLIGHT

US$9.7 billion in investment in cellular agriculture globally and growing over the last several years.

Canadian investors, such as the **Canadian Pension Plan Investment Board** and **Ontario Teachers' Pension Plan**, see the potential and **are investing in cellular agriculture**.

Celebrities and business leaders such as Robert Downey Jr., Leonardo DiCaprio, Ashton Kutcher, Bill Gates and Richard Branson are advocates of and **have invested in cellular agriculture companies.**

Table 1. Recent investments in cellular agriculture companies by Canadian investors

Company	Country	Year	Investment (million USD)	Notes
Perfect Day	US US	2020 2021	300 350	Series C round, Canada Pension Plan Investment Board (CPPIB) was lead investor with $50M Series D round, co-led by Temasek and CPPIB.
Upside Foods	US	2021	161	Series B round, previous investments included Builders VC, who have offices in Calgary
Mosa Meat	NLD	2021	85	Series B round, which included Toronto-based venture capital firm ArcTern Ventures
Motif FoodWorks	US	2021	226	Series B round led by Ontario Teachers' Pension Plan Board and including Wittington Ventures, based in Toronto
Eat Just, Turtle Tree Labs, Sing Cell	US, Singapore		Not available	Eat Beyond, a Vancouver-based venture capital firm, is focused on alternative proteins
Avant Meats	Hong Kong	2020	3.1	Seed round, Loyal VC, who have offices in Toronto
Eat Just, Biftek, Mogale Meats, Novel Farms Inc., MeliBio, Inc., CELL AG TECH	US, South Africa, Turkey, Canada	2021	Not available	CULT Food Science, an investment platform based in Vancouver, is focused on "lab-grown food" and has invested in Canadian cultivated seafood company CELL AG TECH

Regulatory Implications

Globally, regulatory approval remains one of the most important challenges facing the cellular agriculture industry. Jurisdictions with transparent and timely-yet-stringent regulatory processes will be more likely to emerge as world leaders in cellular agriculture.

Many countries have adopted proactive and advanced approaches towards the regulation of cellular agriculture products. In the US, new food ingredients produced by cellular agriculture for the domestic market can seek Food and Drug Administration (FDA) approval through GRAS (Generally Recognized As Safe) if their conventional product counterpart is in the GRAS list. Through this process, *Perfect Day's* whey protein approval took ten months.[84] The USDA and the FDA released a formal agreement to create a joint regulatory framework for cell-based meat product approvals.[85] The Alliance for Meat, Poultry & Seafood Innovation (AMPS Innovation), a coalition of cellular agriculture companies, works together to advocate for a transparent path to market for their products and to help inform new regulations.[86]

In 2020, Singapore was the first country to grant regulatory approval to cultivated meat, with *Eat Just* cultivated chicken as an ingredient in chicken bites.[70] The early engagement of regulators in Singapore has helped facilitate safety testing and regulatory approval and has now led to a framework to evaluate cultivated meat products within the Singapore Food Agency's novel foods designation.[87] In the European Union (EU), cultivated meat will be regulated as part of the EU's Novel Food Regulation published in 2018. While this process allows for EU-wide approval, it takes 18 to 24 months.[88, 89] Likewise, in Israel, cultivated meat will be regulated as a novel food to align with European regulations.[90]

In Canada, cellular agriculture products are not currently subject to the same policies and regulations as other agricultural products. Any cellular agriculture food product

will be considered a 'Novel Food' by Health Canada and assessed as such.[91] Soy leghemoglobin (LegH) in *Impossible Foods*[20] was recently approved in Canada through this process. Engagements between Canadian regulators and the industry have led to a better industry understanding of Canada's regulatory requirements and their options for flexible and case-by-case science-based data submissions. Additionally, the industry is encouraged to engage regulators as early as possible and throughout their product development cycle by requesting confidential pre-market submission consultations to discuss pre-market safety assessment requirements. Such interactions with the industry also provide regulators with opportunities to better understand 'what's in the pipeline.' Of note, production and manufacturing facilities require separate approvals from the novel food product.

One additional consideration in Canada and globally is the labelling and naming requirements for cellular agriculture products both from a regulatory and consumer perspective. Suitable naming conventions are being explored, but are not yet decided upon.[92, 93]

When considering a future regulatory process for cellular agriculture products in Canada, existing global models should be evaluated for efficacy and alignment with Canada's stringent safety requirements. Canada should strive to align its regulations with those of trade partners.[94] There is an opportunity for Canada to set the regulatory agenda and attract companies that want to be closer to the economically important Asian and US markets. Canada can also work with other countries for cross assessment of regulatory processes, as is currently being discussed between Canada, Singapore, Australia and New Zealand around cellular agriculture products.[95] Based on a shared assessment approach, this would avoid duplication and streamline product approval. This process is currently being trialled for genetically modified (GM) food products between Health Canada and Food Standards Australia New Zealand.[96] Moreover, Canada's regulatory system demonstrated its agility during the COVID-19 pandemic. Lessons learned from pandemic regulatory experiences could inform future agility of regulatory processes for innovative technologies, including cellular agriculture.

By Dr. Michael von Massow

Economic Analysis Highlights Opportunity and Benefits to Canada

The World Bank estimates that agriculture and food represent US$8 trillion or 10% of the total global economy.[97] Primary agriculture is estimated to produce US$5 trillion in value at the farm level, with the remainder representing value-added food processing activities. While the added value is much higher in developed countries, there is much less food processing in developing countries; therefore, the proportion of food processing in the global number is lower. As highlighted above, traditional agricultural production will not keep pace with the growth in food demand as income and population rise. Additionally, there is concern about the environmental impact of current and expanded traditional food production (see Background).

Canadians spend almost $130 billion annually in grocery stores[98] and an additional $75 billion in food service.[99] This represents a significant opportunity worth nearly $210 billion annually for domestic producers and processors, equal to approximately 2% of the global food expenditure. Canada's production sector is a critically important part of the economy, with farm cash receipts in 2020 being $72 billion, 38% of which are livestock products and 62% crop receipts.[100] This reflects the high value of Canadian food exports. In 2020, agri-food products represented approximately 10% of Canada's goods exports and were worth over $74 billion, representing approximately 5% of the world trade in food and agriculture products.[101] Canada has an aggressive target for growth for agri-food exports, which are a vital driver for post-COVID economic recovery. As we outlined earlier, the Agri-Food Economic Strategy Table highlighted innovation and value-added opportunities as one of the key themes to achieve this aggressive growth target. The Canadian Federation of Agriculture, the Canadian Federation of Independent Business, and the Canadian Chamber of Commerce have all highlighted the importance of agriculture and food in driving the post-COVID economic recovery.[102, 103, 104]

By Dr. Michael von Massow

Cellular agriculture is expected to provide viable alternatives to a wide variety of agricultural products and food ingredients. While cultivated meat receives the most attention, the potential for a wide range of products and ingredients is immense. As the technology develops, growth in the market will be exponential as this vast array of new products emerges.

Estimates of sales of cellular agriculture products vary considerably given the uncertainty around new product development, scaling, costs, regulatory approvals, and other factors. Estimates range from a low of US$19 million by 2027 (cultured meat only) to a high of US$95 billion by 2030 (all of cellular agriculture) (see detailed table in Appendix A). It is reasonable to expect that the market for these products will be in the billions over the next ten years and likely to be in the tens of billions with exponential growth. As an example, the most optimistic projections of US$95 billion by 2030 are forecasted to grow from US$29 billion in 2026. Cellular agriculture presents a significant opportunity for growth in economic activity and exports to complement Canada's core agriculture strengths. It is worth noting that the size of the market is less uncertain than the timing of the market. This market will grow and present a significant opportunity; the question is the rate of growth over time.

The opportunity for Canada depends on a variety of factors. Using the Delphi approach, a well-accepted tool in developing forecasts for new products, our economic analysis developed pessimistic, moderate, and optimistic scenarios for both the size of the global market and the share of that market that Canada can capture in that timeframe. Rather than assign a specific dollar value to a year (as many other estimates did), we specified numbers on a growth path. These are presented in Table 2. The moderate growth and moderate share scenario (global sales of $75 billion and a 2% share for Canada) suggest a $1.5 billion a year industry, and the optimistic scenario for 2030 (global sales of $150 billion and a 5% share for Canada), suggests a $7.5 billion a year industry. This is consistent with some of the 2030 estimates outlined in Appendix A. The most optimistic scenario (global sales of $250 billion and a 5% share for Canada) suggests a $12.5 billion a year industry. We reiterate that the rate of growth is less certain than the fact that the industry will grow, so the total market potential is relatively certain, and total sales will grow as the market grows without a change in the share of that growth.

SPOTLIGHT

The Canadian cellular agriculture industry could reach **$7.5 billion/year** and create up to **86,000 jobs** by 2030, and up to **$12.5 billion/year** and create as many as **142,000 jobs** over a longer time frame.

Table 2: Market Potential and Growth Path for Cellular Agriculture in Canada

	Canada's Share (CDN)		
Size of Global Market	1%	2%	5%
10,000,000,000	$ 50,000,000	$ 200,000,000	$ 500,000,000
25,000,000,000	$ 125,000,000	$ 500,000,000	$ 1,250,000,000
75,000,000,000	$ 375,000,000	$ 1,500,000,000	$ 3,750,000,000
150,000,000,000	$ 750,000,000	$ 3,000,000,000	$ 7,500,000,000
250,000,000,000	$ 1,250,000,000	$ 5,000,000,000	$ 12,500,000,000

Note: ***Canada's Share:*** **2%** represents Canada's approximate percentage share of the global food expenditures, and **5%** represents Canada's current percentage share of the world trade in food and agriculture products. ***Size of Global Market:*** $10 billion reflects a significant but lower estimate of global market size with an adjustment to include all cellular agriculture products from a consideration of cultivated meats only. We also extended earlier estimates out to 2030, a reasonable time horizon for growth and development both globally and in Canada, and one which allows for some of the exponential growth that one would expect in a market such as this. The midpoint of $75 billion is below some of the estimates for 2030 but represents a conservative forecast for the next decade. The most optimistic forecast of $250 billion is included to highlight the potential market size 20+ years down the line.

Investors are seeing the potential in cellular agriculture. It is sometimes difficult for Canadian firms to leverage investment (although there are some examples) as many venture capital firms are based in the US. In fact, as indicated earlier, the CPPIB as lead investor invested $50 million of the expanded (Series C) and more recently co-led the $350 million Series D funding round in US-based *Perfect Day*, which creates dairy protein in a yeast fermentation process. The CPPIB leadership declared alternate proteins "the most important market opportunity versus impact on the climate." In the right environment, Canada is well-positioned to lead in cellular agriculture and to derive significant value out of that leadership.

Government investments in agriculture have yielded significant returns in the past. While investments in cellular agriculture come with some uncertainty, investments in technology and scale-up infrastructure could be expected to deliver similar or better rates of return. Gray and Malla[105] undertook a review of studies and found an average annual rate of return of almost 60% to investment in research across all studies. Fan[106] found that annual rates of return to agricultural research in China ranged from 36% to 90% and increased over time as the technology was adopted. While not specific to Canada, it highlights that returns increase over time as technology is implemented and the market grows. These estimates of return are likely low across the life of a technology because they are taken at a specific point in time before the end of life for the technologies. Malla and Brewin[107] compare different technologies in a Canadian context and assert that the estimates of returns are reasonable. Once again, these estimates are point estimates rather than lifetime estimates. They highlight that government investment often encourages increased private sector investment as well.

The estimates above indicate that cellular agriculture products have the potential to create significant economic activity. It is expected that North America and southeast Asia will be the first markets to grow, and Canada is well-positioned to serve both markets. Canada also produces a ready supply of inputs into many cellular agriculture processes, providing a competitive advantage. Canada has world-class research universities and well-developed infrastructure to bring products to both domestic and international markets.

There remains some concern regarding the infrastructure to scale cellular agriculture products from the lab bench to commercial quantities. This is not just a Canadian issue but a problem worldwide. While the timing of the emergence of these products will not provide a substantive contribution to the 2025 export objectives from the Agri-Food Economic Strategy Table, a well-funded and developed cellular agriculture sector in Canada could help to drive the volume of export increases that are a priority for the Government of Canada. The industry is already developing in both the US and Asia, and moving quickly is essential to leverage these competitive advantages and capture a share of that opportunity for Canada.

This sector can drive sales in Canada and export markets while providing high-value jobs in the Canadian economy. Food manufacturing represented almost 250,000 jobs in 2019, which decreased to below 240,000 in 2020.[108] While there is considerable concern about the availability of labour in both food processing and primary agriculture, jobs in cellular agriculture will be more technically skilled making them more appealing and stable. This expansion of well-paying employment in food production and processing would support a more robust agri-food economy. Canada's food processing sector generates one job for every $416,000 in sales. It is a mature

market with most jobs in production. Canada's biotechnology industry generates one job for every CDN$87,000 in sales. This number reflects that many companies are in the early stages of product development and have a lower revenue relative to employment. As an industry grows and matures, the rate of job growth relative to total revenues slows. In that respect, the cellular agriculture sector in Canada would be job intense in the first years. This suggests that the moderate scenario of $1.5 billion could represent from a low estimate of over 3,600 direct industry jobs (a mature market) to over 17,000 highly skilled jobs in a growing market like biotechnology. In the optimistic scenario for 2030, $7.5 billion could represent from 18,000 to more than 86,000 jobs. Longer-term optimistic estimates suggest potential Canadian revenues as high as $12.5 billion with between 30,000 and 142,000 jobs created. There is also the potential for other positions within the value chain, although there are likely some synergies within other value chains. A more detailed breakdown of these employment estimates is available in Appendix A.

The growth of cellular agriculture could complement Canada's current production. Consumers in both Canada and beyond are diversifying their portfolio of food choices. As incomes rise and our population grows, demand for food will increase, but the increase in choice may mean that current products will not grow or shrink. To continue to grow both production value and exports, Canada would ideally produce a broader range of products. Diversification improves economic resiliency and reduces risk due to losses driven by changes in demand or production issues arising from climate change, such as drought or other factors. Market supply diversification can also improve food security in both Canada and other markets as the overall food supply grows. The growth of this market will also provide alternate markets for producers of feed stock products.

Canadians are becoming increasingly attuned to the issue of climate change and emissions associated with food production. A thriving cellular agriculture sector would provide the potential for production and value-added growth without significant increases in emissions. This characteristic may well make cellular agriculture products more appealing to consumers and spur growth.

Canada is exceptionally well positioned to lead in this emerging sector of the agri-food system. It is critical to create an environment that fosters research and product development. It is also vital to foster an investment climate that allows an industry to grow and flourish in Canada. A thriving cellular agriculture sector requires the proactive development of a regulatory framework that enables products to be developed, tested, and brought to market. Although other jurisdictions are currently ahead of Canada in this regard, we have a huge opportunity for economic activity and growth driven by cellular agriculture in a global market expected to approach US$100 billion in the next decade. Leveraging and fostering that growth will facilitate capturing that opportunity for Canadians.

Key Considerations and Stakeholder Insights for an Emerging Cellular Agriculture Industry in Canada

A series of stakeholder interviews and focus groups were held between March - June 2021 to explore key considerations for Canada's emerging cellular agriculture industry (see Appendix B for methodology and detailed analysis). Stakeholder representation was broad and included Canadian and international industries (cellular agriculture, food and beverage, conventional producers, related health sectors), academia, investors, funders, policymakers, government, and not-for-profit organizations. Dominant consultation perspectives were analyzed in conjunction with existing data on the global industry and the Canadian ecosystem to feed into actionable priority opportunities for a thriving Canadian cellular agriculture industry.

Consultation participants widely advised that there is space in the global cellular agriculture market for Canada to become a leader. However, this window is rapidly closing, and Canada should act now to maintain competitiveness in an evolving protein landscape or risk falling behind. This is particularly true when compared to leading countries such as Singapore, Israel, the Netherlands, and the US. Canada has unique advantages, including an already strong agriculture and agri-food sector, an extensive food and beverage industry, free-trade agreements covering 60% of global GDP[109], readily available feedstock, and world-class expertise. Canada also has strong drivers to develop a Canadian cellular agriculture industry which includes mitigating the negative impact of climate change on conventional agriculture production, an economic opportunity worth up to $12.5 billion, and the vision of the Agri-Food Economic Strategy Table for Canada to be the favoured protein provider globally.

Potential economic benefits of developing a domestic cellular agriculture industry include company creation and/or diversification, Canadian IP, export opportunities, and high-quality job creation.

Furthermore, it is anticipated that cellular agriculture, when produced at scale, could offer vital sources of macronutrients and less expensive protein sources to individuals and populations that cannot afford a consistent supply of animal-based products or existing plant-based alternatives. Government incentivization and support, as well as the development of national strategies and regulatory frameworks for building a cellular agriculture sector, have been crucial in the emergence of the industry in countries currently leading in cellular agriculture. There was agreement that, for Canada to develop its own cellular agriculture industry and be a leader in this rapidly evolving space, the sector will likewise need strong support from federal and provincial/territorial governments organized around a Canadian national cellular agriculture strategy that accounts for regional priorities and strengths. As in other jurisdictions, an essential component of a successful Canadian strategy will be a flexible, iterative, and transparent regulatory environment, developed in conjunction with technological advances and in consultation with stakeholders. A critical consideration for a growing domestic cellular agriculture industry would be its role in the broader agriculture industry, complementing conventional agriculture through diversification and creating new product categories, not supplanting it. While there was some concern that cellular agriculture could result in job displacement, this is more likely to be considered within the broader dynamics of generational turnover than as an abrupt job decrease, allowing for skills development of new generations and strategic location of cellular agriculture facilities in regions across Canada.

A prevailing theme was that for Canada to become a world leader in this sector, government funding should be substantial, sustained, and consistent to provide the necessary support for developing this new sector. Funding agencies should support academic research while providing opportunities for industry-driven R&D. Investment in research/innovation hubs, including incubators and accelerators, would support Canadian start-ups and entrepreneurs working in the cellular agriculture space by providing them with access to facilities (e.g., affordable lab space), mentorship, and investment opportunities, as well as facilitate knowledge sharing. In addition, infrastructure for pilot/demonstration scale-up and commercial-scale production would be critical and significantly benefit companies aiming to get products beyond proof-of-concept and ultimately to market. Canada can further support the growth of this industry by incentivizing public-private partnerships and multi-, cross- and trans-disciplinary networks, and by developing expertise and highly qualified personnel (HQP) for the sector, including raising awareness in existing talent from complementary disciplines. Investing in the technologies underpinning cellular agriculture, in particular engineering biology and 'omics, will lead to advances that can equally be applied to fields such as medical sciences, waste/by-product valorization and upcycling, and biomaterials production, resulting in cross-sectoral technological benefits for sectors such as health and low carbon manufacturing.

Private investment is also a crucial funding route for the cellular agriculture industry and is frequently leveraged by public investment. The tremendous amount of private capital that has entered the industry in the US builds on multiple billions of dollars' worth of public funding into the broader technology space (e.g., engineering biology) by the US Department of Defense, Defense Advanced Research Projects Agency

(DARPA) and the Department of Energy.[64, 65] As described previously, other countries leading in this space have also developed their cellular agriculture industries with high levels of direct public funding in combination with targeted government programs to attract or leverage private investment. Canadian public investment will be essential for attracting and leveraging private investment and corporate partnerships to develop the necessary supportive ecosystem for cellular agriculture companies.

Canadian regulatory and labelling requirements, described in the above Regulatory Implications section, were generally characterized by consultation participants as extremely time-consuming, unpredictable and opaque. Efforts have been made to mitigate this issue, including encouragement for producers of novel foods to engage both early and often with regulators, taking advantage of the pre-submission consultation process. Agriculture and Agri-Food Canada can offer support by providing information and increasing awareness and understanding of the regulatory approval process. Additional efforts have been made to improve regulatory transparency, with commitments toward modernizing regulatory review processes.[110] Despite this, regulation is still perceived as a major barrier to innovation and hence to investment in cellular agriculture. There was concern that the approval process could be even slower for products produced through cellular agriculture than for other novel foods, and that the domestic policy environment is not flexible enough to support start-ups developing food production technologies not yet foreseen or imagined. Without addressing these regulatory hurdles and proactively developing a clear and supportive pathway for safe cellular agriculture products to enter the market, it will be challenging to attract and retain cellular agriculture companies in Canada and encourage significant private sector investment in a domestic cellular agriculture sector.

Consumer acceptance and consumer perception were raised frequently during consultations. Regulation and trust in safety processes and standards will be critical to consumer acceptance of cellular agriculture food products, and this information should be part of a broader strategy of education and engagement. Research is needed to understand consumer risk perception and consumer preferences to develop an effective communication strategy. Consumer engagement must start early, in parallel with product development, and communications should reach all members of society in ways that engage different demographics with varying opinions. Strong government support for the cellular agriculture industry will assist with building consumer confidence in these products.

While changes have already occurred in the protein industry over the last several years (e.g., plants, insects, etc.) and shifts in the new protein industry will continue over the next generations based on global needs and consumer demand, it was clearly articulated during consultations that investing in cellular agriculture and committing to a vision of Canada as a global leader does not and should not diminish the importance of domestic conventional agriculture and food production. Canadian producers can embrace areas of complementarity and strategies to help ensure an integrated and sustainable future, including new markets for raw materials (feedstock), enhancing current products, creating new product categories and diversifying product offerings, and exploring new business opportunities in the emerging industry.

Given the innovative nature of these technologies, there is a pressing need to ensure that we have a domestic workforce that is trained in the right skills, or that those with the existing skills (e.g., from health and industrial biotech) are informed about the

opportunity and provided with the resources necessary for them to shift their focus to this new industry. Canada already benefits from world-class universities and colleges. By deliberately bringing together science, technology, engineering, social sciences and related sectors (e.g., food and nutritional science, culinary arts, etc.) we can further support innovation and training for the future cellular agriculture workforce.

Canada's Actionable Opportunities for a Thriving Cellular Agriculture Ecosystem

Based on the input from our stakeholder consultations, along with a review of literature and other publicly available information, we articulate the inter-connected actionable opportunities to inform a policy framework and implementation plan for a thriving Canadian cellular agriculture industry worth up to $12.5 billion a year and creating up to 142,000 jobs.

1. Develop a National Vision and Strategy for a Canadian Cellular Agriculture Industry in the Near Term to enable a domestic ecosystem that fully realizes the benefits presented by this industry. Founded on a clear value proposition and rationale, this strategy should be national in scope and developed collaboratively and cohesively by federal, provincial and territorial governments, industry (including large corporates, start-ups and conventional agriculture), academic and research institutions, not-for-profits, regulatory agencies, and policymakers.

The strategy should define a framework with concrete steps for implementing an action plan in the short, medium and long-term and have clear success metrics. Considerations for the value proposition and rationale include economic and export opportunities, environmental and ethical concerns, current and future domestic and global protein requirements, trade considerations, the changing food and agriculture employment landscape, opportunities in the sector, food security, resiliency in the face of climate change or other shocks, and alignment with Canada's strengths and priorities. In addition, promoting the integration of new production systems with existing conventional ones is critical, with ongoing monitoring to prevent undue disruption to either sector. The framework should include the strategy for government

incentivization at both federal and regional levels. In the development of this Canadian-specific framework, models from currently leading cellular agriculture countries should inform pathways for incentivization and funding mechanisms that leverage government support for private sector investment.

Taking the value proposition into account, the action plan should specifically include steps for:

- Substantial and sustained investment in cellular agriculture for dedicated research and development;
- Support for start-up creation and growth through pilot scale-up to commercial-level production;
- Building a talent development pipeline.

The action plan should ensure coordination of and access to essential and existing infrastructure. Upfront investment is necessary to help Canada catch up with other jurisdictions currently ahead in this sector.

Broad communication and outreach are integral to the success of a national strategy. This needs to occur in parallel with technology development to ensure widespread uptake of cellular agriculture products and optimal return on investment. Critical consideration is required to understand consumer perspectives and use for appropriate messaging to reach various people across different demographics - from children to the elderly, as well as those facing food insecurity - to articulate benefits, address concerns, and overcome potential barriers early.

2. Establish a Clear and Transparent Regulatory Framework for Cellular Agriculture Products in Canada. Canada is encouraged to develop an agile, iterative, and innovative regulatory framework by building on existing processes. The framework should be informed as early as possible by engaging industry stakeholders and other experts with the relevant regulatory departments and agencies (e.g., AAFC, CFIA, Health Canada and Environment and Climate Change Canada), and including cellular agriculture subject matter experts within regulatory bodies. This will ensure that any new policies and regulations have expert input and consider the perspectives of both regulatory agencies and the ultimate end users, and would help simplify and strengthen the Canadian process. A timely, reasonably priced and predictable regulatory process, and a smooth and transparent evaluation process with high approval confidence, can be achieved through an iterative approach. Early engagement between regulators and companies also allows issues to be flagged and addressed promptly. This will be crucial to attract and retain cellular agriculture companies in Canada while ensuring the domestic industry remains globally competitive under Canada's rigorous regulatory process and food safety standards. This process can be further fostered through continuous, clear, and comprehensive communication between the industry and regulators, as well as broad dissemination of positive engagements and success stories. A delineated regulatory pathway that is aligned with the industry's needs has shown much success in Singapore, the most advanced jurisdiction in regard to approvals of cellular agriculture product offerings.

To aid companies in navigating the regulatory process, a government program that appoints industry liaisons or "concierges" could be established. This would particularly benefit start-ups and early-stage companies that are navigating the process for the first time. It is anticipated that, before seeking regulatory approval, standardized safety

testing of cellular agriculture food products could provide confirmation of product composition, nutritional profile, and (lack of) toxicity profile. Consideration should be given to an expedited review of products that have already been "passed" by an accredited, external standardized test. As the global cellular agriculture industry grows and matures, Canada will need to ensure its cellular agriculture standards align with emerging international standards to maintain its reputation as a producer of safe, high-quality foods and not impede exports. Currently, this is an underdeveloped area, and being an early mover in standardized safety testing will allow Canada to have substantial input into international standards as they progress. Cross assessment of regulatory processes with other jurisdictions (e.g., Singapore, Australia and New Zealand) should be continued and expanded, as appropriate.

Early development of regulatory guidance for the labelling of these products is also essential for transparency and to empower consumers to make informed choices. Cellular agriculture product labelling should be descriptive, communicate the nature of the product in clear and relatable language, while maintaining appeal as a food item. Labelling should differentiate cellular agriculture products from those in the traditional protein market while creating a positive impression and ensuring both types of products are on a level playing field and competitive in consumer markets.

3. Provide Supporting Mechanisms for Research and Commercial Development. Incentivization, through both public and private investment and partnerships, and outcomes-driven networks, is critical for a thriving domestic cellular agriculture industry, with infrastructure support for R&D, training, company creation, scale-up, and growth leading to made-in-Canada product commercialization.

Research and training the next generation of skilled workers

Early government investment would catalyze invention, help de-risk opportunities, and attract private sector investment while incentivizing innovation and driving company creation and entrepreneurship within Canada. Funding could support:

- Both fundamental and industry-driven research to ensure that the necessary and foundational tools and technologies are in place and that research is directed to industry needs.
- Open science to reduce redundancy and speed up product development.
- Alignment with strategic government focus areas or grand challenges, such as climate action, to encourage industry growth through sustainable practices and innovations.
- Key areas of multi, cross- and trans-disciplinary research (e.g., 'omics, engineering biology, AI, food sciences and others) for advancing cellular agriculture technologies that are also applicable to other business verticals (e.g., health, low carbon economy).
- LCAs, TEAs and other analyses that are objective and independent.
- Social sciences research playing a critical role in driving consumer engagement, addressing risk perception and public trust, and developing appropriate communication strategies.

New training programs that offer targeted and cross-disciplinary opportunities and industry placements related to cellular agriculture and engineering biology are critical. There are also opportunities to train and up-skill those with related expertise in other sectors. This would ensure that a domestic talent pipeline of skilled High-Quality Personnel (HQP) could fill the high-quality jobs that the cellular agriculture industry will create.

Growing the economy through start-up support, public private partnerships, and networks

Early start-ups require support in the form of lab space, facilities, and infrastructure, but also public and private seed funding for initial company growth. Canadian and international investors should be incentivized to invest in Canadian companies through clear and well-publicized government support for the industry. As seen in leading cellular agriculture jurisdictions, investment in public and private sector-partnered innovation hubs, including incubators and accelerators, can effectively support companies in their early stages. In addition to physical facilities, these hubs would need to include access to expertise, mentorship, and investment opportunities. While Canada has some capacity in Nova Scotia and New Brunswick, a lack of facilities for pilot/demonstration scale-up and at commercial scale is viewed as the most significant bottleneck globally, and is a primary reason for companies to leave Canada for other jurisdictions, such as the United States or Europe. The initial outlay to establish domestic scale-up capacity in localized ecosystems would be high, but fee-for-service operations could provide a global leadership opportunity to Canada, with potential to attract foreign companies. Such infrastructure can also be adaptable to serve different industries, such as to the production of vaccines in a health emergency or to bypass disruptions in the supply chain of critical materials to support a low carbon economy.

Supporting applied research and commercial development through industry and research collaboration is valuable to ensure the success of the domestic cellular agriculture industry. Partnerships between established companies and start-ups/academics (public-private partnerships) bridge the gap between research and translation, provide access to infrastructure, and create linkages and entry routes into the supply chain for B2B companies. The larger partner benefits from priority access to innovations, diversification and the creation of new product categories with strong market pull. Effective industry partnerships are vital to inform and drive policy and regulation and advocate with a common voice for a clear path to market for Canadian companies. On a larger scale, outcomes-driven networks are crucial to bringing together diverse stakeholders from industry, academia, government, and non-governmental organizations. Such networks should include diverse fields of multi-, cross-, and trans-disciplinary expertise and platforms and include regional, national, and international partnerships for interdisciplinary cross-pollination of ideas to breakdown silos between sectors and geographic regions and facilitate dialogue between disciplines. Network participants can benefit from and provide benefits to other sectors (e.g., health, low carbon economy) through knowledge exchange and parallel applications of novel technologies. These networks must include representation from the food production and conventional agriculture industries to foster mutually beneficial relationships, and transition or expansion to new food products market.

Moving Forward

Globally, the protein sector is at a crossroads. As a vital engine of economic growth, new technologies and innovations are needed to sustainably meet the increased needs of a growing global population. With many consumers increasingly seeking out new and alternative forms of foods, alongside the damaging effects of climate change on current food production methods, the existing food system is ripe for disruption, and new food production systems including cellular agriculture will be key to meet evolving consumer demands. Canada has a considerable opportunity to capitalize on the rapidly evolving and growing cellular agriculture industry worldwide, with a wealth of domestic expertise, a strong agri-food sector and access to export markets. By taking action on the priorities outlined in this report, Canada has an opportunity to diversify its food and agriculture sector, become a leader in the new global landscape, meet sustainability and food security goals, and reap the benefits from new economic markets. **Momentum in cellular agriculture is advancing globally; now is the time for Canada to capitalize on this potential $12.5 billion a year economic opportunity that can create up 142,000 jobs across the country.**

Appendix A – Economic Analysis

By Dr. Michael von Massow

Our estimates of the potential of cellular agriculture for Canada are based on three key steps:

1. Estimating the size of the cellular agriculture market worldwide;
2. Estimating the size of Canada's share of that market; and
3. Estimating job creation in similar industries at similar levels of development.

There is little doubt that cellular agriculture has huge potential globally. There remains considerable uncertainty about both the rate of growth of the market and Canada's ability to carve out a share of that market. This uncertainty could be reduced if Canada was more proactive and developed a plan for supporting and fostering the industry. We develop projections based on a number of assumptions outlined in this appendix. We also outline some of the uncertainties associated with these assumptions to contextualize the projections and the range of potential outcomes. We highlight that there is likely greater uncertainty with respect to when specific market revenues are achieved as compared to the potential size of those markets.

The Market for Cellular Agriculture Products

Cellular agriculture covers a wide range of products. The primary focus of analysts to date has been on meat and dairy proteins. Many of the estimates of market size are based exclusively on lab-grown meat rather than on the broader potential, which includes cultured non-protein food products like chocolate[50] and many fermentation products as ingredients. An example of this is heme which is used in some plant-based proteins to mimic real meat proteins.[111] This makes estimation of the potential size of the market more difficult. There will be growth in existing products, but there will be new products still in early development that will drive the substantial growth in cellular agriculture as they are commercially scaled and come to market. There is little debate that there will be substantial growth in the cellular agriculture market. There is less consensus on the pace of that growth and when the market will meet certain revenue milestones.

We collected a broad range of estimates of the size of the cellular market generally or cultured meat specifically. This Delphi approach integrates a broad range of perspectives to provide insight into the potential for cellular agriculture products. The Delphi approach is a well-accepted tool in developing forecasts for products/segments for which there is no significant history. Table A1 provides a listing of the various estimates that informed our forecasts.

We choose to evaluate a range of market sizes. Rather than assign a specific dollar value to a year (as many of the other estimates did), we specified numbers on a growth path. There is less debate on the eventual size of the market than there is as to when we will hit those milestones. Our low value of $10 billion reflects a significant market but incorporates the lower estimates of global market size with an adjustment to include all cellular agriculture products when only cultured meats were estimated. We also extended estimates before 2030 out to 2030. This represents a reasonable time horizon for growth and development both globally and in Canada and allows for some of the exponential growth one would expect in a market such as this. The midpoint of $75 billion is below some of the estimates for 2030 but represents a conservative forecast reflecting some of the more pessimistic forecasts for the next decade. We would reiterate that there is little doubt that the market will reach $75 billion and beyond globally, but it might happen a bit later than 2030. The most optimistic forecast ($250 billion) is included to highlight the potential market size twenty or thirty years down the line.

There are a number of factors that will affect the size and growth rate of the cellular agriculture market, which brings some uncertainty as to the timing of specific revenue milestones. These should be acknowledged as contributing uncertainty for both the total market size and the share attributable to Canada. These include:

- The pace of discovery and product development for individual products. Many products are still in the early development phase and even more in the discovery phase. The ability to bring these products to market and scale them depends on financing, infrastructure, and other factors.
- Consumer acceptance of these products. There is evidence that consumers are open to these products. Plant-based products such as the *Impossible Burger™* include the cellular agriculture product heme and are experiencing significant growth. Cultured chicken is on the market in Singapore. *Perfect Day* is selling frozen dessert and cream cheese with

cultured dairy proteins, and *The EVERY Company* has launched an egg white-equivalent protein.

- Regulatory frameworks will be important for bringing products to the market.
- The availability of investment to drive product development and scale-up will factor into the rate of growth.
- Infrastructure in support of scaling products is also critical to market growth.

It is also worth noting that much of the expertise and infrastructure to succeed in the cellular agriculture market will be applicable beyond food and ingredients. Chiu et al.[42] estimate that the market for biological-based innovation will reach $3.0-$5.1 trillion by 2050, with $0.8 -$1.2 trillion of that in agriculture and food. Fostering the cellular agriculture market will provide an opportunity to develop a critical mass of highly qualified personnel and infrastructure to facilitate growth in the broader field of bio-innovation.

Table A1: Estimates of Cellular Agriculture Market Size

Estimate	Parameter	Source
Worth $1.66 billion by 2031	Global cultured meat market - uses lab-grown animal cells to create meat products without requiring animal slaughter	https://www.idtechex.com/en/research-report/cultured-meat-2021-2041-technologies-markets-forecasts/815
Worth $11.13 billion by 2041	Global cultured meat market - uses lab-grown animal cells to create meat products without requiring animal slaughter	https://www.idtechex.com/en/research-report/cultured-meat-2021-2041-technologies-markets-forecasts/815
Worth $28.60 billion by 2026	Cellular agriculture - uses tissue engineering techniques to manufacture meat and dairy products that are molecularly identical to those produced by traditional methods	https://blog.marketresearch.com/cultured-meat-market-to-reach-94.54-billion-by-2030
Worth $94.54 billion by 2030	Cellular agriculture - uses tissue engineering techniques to manufacture meat and dairy products that are molecularly identical to those produced by traditional methods	https://blog.marketresearch.com/cultured-meat-market-to-reach-94.54-billion-by-2030
Worth $352.4 million USD by 2028	Cultured meat market	https://www.prnewswire.com/news-releases/cultured-meat-market-size-worth-usd-352-4-million-by-2028--cagr-14-9-polaris-market-research-301259363.html
Worth $94.5 billion by 2030	Cultured meat is processed from a living animal by painlessly extracting muscle cells.	https://www.businesswire.com/news/home/20210302005849/en/Cultured-Meat-Market-Report-2020-2021-Global-Regional-Analysis-Forecasts-to-2026-2030---ResearchAndMarkets.com
Market size of $248 million USD by 2026	Cultured meat is described as lab-grown meat created in a culture medium utilizing different tissue and bio-engineered techniques. In vitro meat, clean meat, and synthetic meat are all terms used to describe cultured meat.	https://www.globenewswire.com/en/news-release/2021/06/10/2245335/0/en/Global-Cultured-Meat-Market-Size-Expected-to-Reach-USD-248-Million-by-2026-at-15-7-CAGR-Growth-Facts-Factors.html
Value of $28 billion of 2035	Alternative proteins excluding plant-based	(Witte et al., 2021)
Value of $25 billion by 2030	Cultured meat market	Cultivated meat: Out of the lab, into the frying pan | McKinsey
Value of $214 million USD by 2025	Cultured meat market	https://www.marketsandmarkets.com/Market-Reports/cultured-meat-market-204524444.html
Value of $593 million USD by 2032	Cultured meat market	https://www.marketsandmarkets.com/Market-Reports/cultured-meat-market-204524444.html
Value of $206.6 million USD by 2025	Global cultured meat market	https://www.prnewswire.com/news-releases/global-cultured-meat-market-report-2021-rising-technological-advancements-and-investment-in-new-startups-are-expected-to-boost-market-growth---forecast-to-2025--2030-301297587.html
Value of $2.8 billion by 2030	Cultured meat or in vitro meat offers a safe and disease-free way forward to meet increasing meat requirements without involving animal sacrifices	https://www.prnewswire.com/news-releases/global-cultured-meat-market-2020-to-2030---by-type-end-user-and-opportunities-301312839.html

Global market size of 352.4 million by 2028	The different techniques for cultured meat production include scaffold-based technique, self-organizing technique, cell culture media, and others	https://www.businesswire.com/news/home/20210525005706/en/Cultured-Meat-Market-Report-2021---Global-Share-Size-Trends-Industry-Analysis-Forecast-to-2028---ResearchAndMarkets.com
$21.3 million USD by 2026	Different processed meat products have been manufactured from in vitro meat cultured from muscle tissue, as opposed to the traditional method of slaughtering animals	https://www.verifiedmarketresearch.com/product/cultured-meat-market/
Value of $572 million USD by 2026	Cultured meat – produced in animal with advanced technology, without sacrificing animals.	https://www.marketdataforecast.com/market-reports/cultured-meat-market
$572 million USD by 2027	Cultured meat - a type of meat produced from vitro nature cell by taking different cells from different animals and growth should be focused on the medium which is rich in nutrients.	https://www.databridgemarketresearch.com/reports/global-cultured-meat-market
Market size of $348.8 million USD by 2028	Cultured meat market	https://www.marketwatch.com/press-release/cultured-meat-market-2021-global-outlook-research-trends-and-forecast-to-2028-2021-07-28?tesla=y
Market size of $285.92 million USD by 2026	Cultured meat market	https://www.researchandmarkets.com/reports/4896478/cultured-meat-market-research-report-by-source
Revenue of $200.2 million USD between 2021 and 2024	Cultured Meat Market analysis considers sales from beef, pork and lamb, and poultry	https://www.ktvn.com/story/43544071/cultured-meat-market-size-report-2021-business-scenario-competition-strategy-and-growth-analysis-top-manufacturers-with-future-scope-forecast-to-2024
$19.8 million by 2027	Global synthetic (cultured) meat market	https://www.bccresearch.com/market-research/biotechnology/synthetic-cultured-meat.html

The Canadian Share of the Cellular Agriculture Market

There is considerable uncertainty related to the share of the total market that Canada could reach. As outlined above, factors such as availability of investment, supporting infrastructure for scaling, regulation, and Canadian-based discovery and development will influence whether Canada plays a significant role in this industry going forward. Canada may also be dependent on other markets for growth. It is often the case that the cost of regulatory approvals for the relatively small Canadian market leads companies to prioritize limited resources for approvals to larger markets. The pace of approval also matters, but Smyth[112] highlights that the approval of GM Arctic Apples in Canada proceeded such that approvals came very quickly after they did in the United States.

Darby and Sewell[113] also highlight a number of other factors that can influence a country's competitive position in new technology development. They suggest that governments need to be proactive in helping companies bring products to commercial success, particularly early investment where the private sector may not step up.

Canada represents approximately 0.5% of the world's population.[114] Our conservative estimate of share reflects the case if Canada achieves a share of the market only equal to double its share of population. We use double because Canada is a developed country and is further ahead in technology and food processing than many developing economies.

The World Bank estimated global GDP in 2019 at USD $87.6 trillion,[97] and that agriculture and food represent approximately 10% of that total. We use the year 2019 as 2020 GDP was lower due to the pandemic and should be expected to return to pre-pandemic levels eventually. Canadians spent almost $210 billion on food in 2019, with approximately $130 billion in food stores[98] and another $78.5 billion in food service.[99] That means that Canada represents approximately almost 2% of the global food expenditure when exchange rates are considered. We use this as the midpoint for Canada's potential share of the total cellular agriculture market.

Canada is a major producer and exporter of agriculture and food products, reaching almost $74 billion in 2020.[101] This represents approximately 5% of the world trade in food and agriculture products of $1.5 trillion.[115] We use this as the aggressive target for Canada's share of the cellular agriculture market. If Canada can compete in cellular agriculture as it does in global exports generally, this is an achievable target.

Job Creation

Predicting job creation is difficult, and forecasts are confounded by the maturity of the market. Jobs are a larger proportion of revenues early in the development of a market as there are many skilled individuals working on product and process discovery and development in advance of a mature market. As markets grow, the rate of job creation decreases.

Canada's gross domestic product (GDP) was almost $1.7 trillion in 2019,[116] with total employment of approximately 19 million people at the end of 2019. That represents an average of slightly more than $89,000 of GDP per job.

Canada's food processing sector produces approximately $104 billion in annual revenue[108] with employment of approximately 250,000 jobs[117] for a revenue-to-job ratio of $416,000. This makes sense in comparison to the Canadian number as the lower number for Canada reflects a significant number of service jobs where labour costs are a bigger component of output.

Canada's biotechnology sector represents almost $90 billion in revenue and one million jobs.[118] This gives a revenue per job ratio of almost $90,000. This is an outproducing industry but has a revenue-to-job ratio closer to the Canadian average. This reflects an industry in its infancy and the requirement to invest in development to grow sales.

We use the biotechnology number for an upper bound for cellular agriculture jobs and the food processing industry ratio for the lower bound. This reflects that job creation is highest early in a market's development before sales grow. It is positive that the jobs are created early in the development of an industry.

Projections

Based on the parameters outlined above, we developed projections for the size of the Canadian cellular agriculture industry.

Table A2: Market Potential for Cellular Agriculture in Canada

	Canada's Share		
Size of Global Market ($)	1%	2%	5%
10,000,000,000	$ 50,000,000	$ 200,000,000	$ 500,000,000
25,000,000,000	$ 125,000,000	$ 500,000,000	$ 1,250,000,000
75,000,000,000	$ 375,000,000	$ 1,500,000,000	$ 3,750,000,000
150,000,000,000	$ 750,000,000	$ 3,000,000,000	$ 7,500,000,000
250,000,000,000	$ 1,250,000,000	$ 5,000,000,000	$ 12,500,000,000

Table A3: Cellular Agriculture Jobs Estimates

	Share		
Early Market ($)	Low	Middle	High
10,000,000,000	568	2274	5684
25,000,000,000	1,421	5684	14210
75,000,000,000	4,263	17052	42629
150,000,000,000	8,526	34103	85259
250,000,000,000	14,210	56839	142098
	Share		
Mature Market ($)	Low	Middle	High
10,000,000,000	120	481	1,202
25,000,000,000	300	1,202	3,005
75,000,000,000	901	3,606	9,014
150,000,000,000	1,803	7,212	18,029
250,000,000,000	3,005	12,019	30,048

Appendix B - Consultation Summary & Analysis

This report explores the potential and ways of advancing the role of cellular agriculture to contribute to sustainable and resilient Canadian food systems and food economies. To this end, the report is based on research conducted to identify key considerations (such as opportunities, benefits, challenges and barriers, priorities) for an emerging cellular agriculture industry in Canada. From these considerations, a series of actions and recommendations for Canadian decision-makers were produced, which will serve to advance a domestic cellular agriculture sector.

The initiative involved a review of current trends and considerations in cellular agriculture and alternative proteins and consultations with over 65 Canadian and international stakeholders and experts in the field. The initiative began with the preparation of a 'discussion document', which presents considerations and opportunities around an emerging and growing cellular agriculture industry in Canada. The document was organized into nine themes: investment and economic growth, technological and industry readiness, applied research, training and practitioners, strategic public-private partnerships, consumer acceptance, health and nutrition, environment, and policy and regulation. These particular areas were selected because they comprehensively cover the different aspects of and considerations around the pipeline for making cellular agriculture a strong industry in Canada, from feedstock and research to industry development and consumer demand. The document was created through an iterative process, which first involved developing a 'strawman' version through a review of academic and grey literature, and then refining and further developing the document based on the feedback of this initiative's collaborators and partners.

The next stage involved semi-structured interviews with 52 Canadian and international expert stakeholders, including those from the federal and provincial governments, academia, start-ups, industry, funders, and NGOs, and participant consent was obtained before commencing the interviews. Approximately half the interviews were one-on-one sessions, with the other half consisting of group sessions ranging from 2 to 8 people (24 sessions were conducted in total). Interview data were transcribed and examined using a two-step thematic analysis approach. The first step employed a deductive approach (i.e., pre-defined thematic framework), which examined the data to identify benefits, challenges, and key actions/priorities for an emerging cellular agriculture industry in Canada. The second step took an inductive approach (i.e., emergent themes), and it involved examining the data associated with each of the benefits, challenges, and actions/priorities categories to identify common themes. The result of this work was a coherent list of benefits, challenges, and key actions/priorities for an emerging and growing cellular agriculture industry in Canada.

The following stage of the project involved a series of three focus groups, consisting of previous (n=23) and new (n=13) participants. The focus groups were organized to critique and refine the list of identified benefits, challenges, and actions/priorities, which was sent to the participants prior to the sessions. Consent was obtained from new participants. The focus group discussions were guided by questions about which benefits, challenges, and actions/priorities appeared particularly important, irrelevant, and/or were missing. Focus group discussions were transcribed, and the data was examined to alter and refine the benefits, challenges, and key actions/priorities list.

The final stage of the initiative involved applying the thematic framework developed for the discussion document to the outcomes of the focus groups. The original framework was refined based on common topics that emerged through the interview and focus group discussions to consist of eight themes (see below): Develop a National Vision; Funding and Investment, including Government and Regulatory Incentives; Economic Development Opportunity and Commercialization; Collaboration, Partnerships and Networks; Research, Technology and Innovation; Public and Industry Acceptance; Food Security and Health; and Environment. The focus group output was organized into 'sub-themes' or common topics/considerations, and the interview data were re-examined to add missing comments, points, and considerations (Table A4).

Table A4. Themes and Subthemes that Emerged from Interview and Focus Data

Theme	Sub-theme (bolded) and description
Develop a National Vision	▪ **Defining the role** of cellular agriculture in Canadian food systems and clearly articulating this role when engaging stakeholders/public to facilitate strategic planning and drive Canada's potential ▪ **National strengths** are identified to clearly demonstrate the opportunity and feasibility of building this industry in Canada ▪ **Regional strengths and interests** are considered when crafting a national vision for cellular agriculture to leverage these and to identify opportunities for building the industry across the country ▪ **Complementarity** between cellular and conventional agriculture is an important component of the national vision to recognize and integrate Canada's current, strong agricultural and food sector ▪ **Public policy** will be developed in alignment with the national vision and will be essential for a coordinated and cohesive effort toward developing a strong domestic cellular agriculture industry ▪ **A systems approach** to recognizes relationships between different regions, sectors, and industries in Canada for a cohesive and effective development of the industry ▪ **The rationale for Canada** should be considered when developing a national vision and should be based on Canada's unique advantages to ensure that Canada can carve its own leadership path within the broader cellular agriculture industry
Funding and Investment, including Government and Regulatory Incentives	▪ **Government Incentivization** through federal and provincial government agencies can stimulate industry growth through numerous mechanisms, including research funding, investment in infrastructure, robust policy, regulatory framework, etc. ▪ **Public funding and in-kind supports** need to be substantial (not incremental) and continued to drive the industry forward to be viable and competitive ▪ **Private funding** (e.g., venture capital) is the most common funding source for cellular agriculture worldwide but is challenging to obtain for early-stage businesses due to long ROI ▪ **Entrepreneurship** is essential to the growth of the cellular agriculture industry in Canada and can be stimulated by public agencies ▪ **Research hubs and incubators** should be developed in a coordinated manner across the country to provide start-ups with access to facilities (affordable lab space, scale-up, etc.), expertise, mentorship, and investment opportunities ▪ **Infrastructure and pilot facilities** should be a priority for piloting and scaling up productions that start-ups and companies can access and achieve scale-up past proof-of-concept ▪ **Regulatory clarity and guidance** are crucial elements to enable innovation and stimulate growth in the industry, and models in leading countries should be examined for their regulatory approach, e.g., Singapore

Economic Development Opportunity and Commercialization	▪ **New employment** and a number of high-quality jobs will be produced through developing a cellular agriculture industry in Canada ▪ **Biomanufacturing technologies and techniques** used in cellular agriculture have applications for a variety of edible and non-edible products, as well as applications in other economic sectors, e.g., health, others ▪ **Conventional agriculture can benefit** from cellular agriculture through forming business-to-business (B2B) relationships with the new, emerging industry, creating high-value cellular agriculture products within Canada ▪ **Upcycling /circular economies** could be supported through the integration of cellular agriculture with other Canadian industries, e.g., using low-value feedstock/by-products ▪ **Attracting and retaining companies and talent** is essential, and consideration is needed to attract, encourage, and train qualified people with the necessary range of experience and knowledge in biomanufacturing to this new and emerging opportunity ▪ **Market opportunities** presented through cellular agriculture have the ability to strengthen Canada's economy through diversification ▪ **Specialization of start-ups and B2B companies** could allow for a more rapid development of a cellular agriculture industry in Canada ▪ **Scaling up solutions** is critical to achieve economies of scale and broad market accessibility/availability ▪ **Corporate and industry engagement** to ensure that cellular products are integrated into established supply chains and distribution networks, as well as encourage private sector investment ▪ **Types of products** include hybrid commodities (e.g., addition of ingredients or cultured meat to plant-based products) that allow start-ups and other companies to move more quickly in bringing products to market by building on commercial precedents ▪ **Regulatory pathways** can be developed through regulator, industry, and public engagement and can be complemented with processes for supporting companies through the regulatory pipeline ▪ **Multiple production and distribution models** exist for cellular agriculture, including establishing it in urban, industrial, rural, and remote places
Collaboration, Partnerships and Networks	▪ **Networks, consortia and public-private partnerships** are important components and best supported by industry-driven networks and partnerships with academia, government, and non-governmental stakeholders to bring key expertise and voices together and include diverse fields of multi-, inter- and transdisciplinary expertise and platforms, ▪ **Regional, national, and international partnerships** are necessary for breaking down silos with different expertise and know-how spread across a large geographic range ▪ **Food product conferences, roundtables and international fora** for convening diverse stakeholders in strategic discussions around issues and ways to support and build industries related to specific food or material products
Research, Technology and Innovation	▪ **Multi-, trans-, and interdisciplinary research opportunities** will advance knowledge in the complex field and industry of cellular agriculture, and there is a need to bundle socioeconomic, cultural, and technological innovation ▪ **Technological advancement** provides enormous opportunities to grow the cellular agriculture industry and engineering biology capacity of Canada in parallel ▪ **Industry-driven applied research** is critical to accelerate commercialization of products and could exist in the form of industry-academia or industry-industry partnerships. ▪ **Canada has a history of innovation** across fields, and parallel technological advancements will be realized through building a cellular agriculture industry ▪ **Innovation hubs** that operate on a regional or nationwide level will benefit research and innovation in cellular agriculture by providing opportunities for research, knowledge sharing, and collaboration, and creation of these types of ecosystems could catalyze innovation, attract companies and drive innovation in the space ▪ **Intellectual property and knowledge silos** are important considerations in order to enable advancement of growth in Canada's fledgling cellular agriculture industry, ▪ **Talent pipeline** considerations must address the fact that cellular agriculture is a complex field that exists at the intersection of multiple disciplines, requiring both diverse and specialized knowledge and providing opportunities for cross-sectoral expertise and potential for re-training

Public and Industry Acceptance	▪ **Public communication, awareness, and trust** require communication strategies that frame cellular agriculture primarily in terms of benefits (e.g., a new source of protein, products, diversification), highlighting complementarity to other methods of production, as well as by prioritizing the development of healthy and safe products and promotion of health benefits (e.g., tailored nutrition and reduced allergenicity) ▪ **Consumer preferences and product appeal** offer choice to consumers and requires products that are on par with the "original" and aligned with consumer preferences ▪ **Consumer perception** of cellular agriculture should be addressed at all stages in the development of a Canadian industry, with clear and consistent messaging from all levels of government and NGO stakeholders ▪ **Affordability and accessibility** of cellular agriculture products is crucial to increase dietary trends toward these foods, but parity of taste and texture is also required to ensure market penetration of these products ▪ **Culture and identity** associated with conventional agriculture could present challenges for widespread acceptance and adoption of cellular agriculture ▪ **Labelling and transparency** considerations include introducing products into the market with clear communication about how they are made, in clear and relatable language (e.g., microbrewery-style production) and names that are both descriptive and appealing as food items
Food Security and Health	▪ **Increasing global food demand** could be in part met through cellular agriculture, as these technologies can help meet needs for proteins, lipids, and synthetic ingredients and the nutritional requirements of a growing global population ▪ **Health and nutrition benefits** could be realized through cellular agriculture, as this food production method could address certain health concerns, such as mercury in fish and antibiotics in meat, and reduce risk of zoonotic disease outbreaks ▪ **Affordability and accessibility** will increase when cellular agriculture is produced at scale, providing a source of affordable macronutrients to various populations ▪ **Portability and localization** of food production could be achieved through cellular agriculture; the industry will likely grow initially through the development of larger facilities, but eventually, facilities can be established in a variety of places, contributing to local food security and economies ▪ **Supply chain resilience** in Canada would be enhanced by cellular agriculture through diversification in the food production system and by feeding into existing or create additional supply chains
Environment	▪ **Life cycle analyses** and techno-economic analyses are critical to improve understanding of cellular agriculture's potential for contributing to environmental and economic sustainability, for example, either reducing GHG's or using them as an input, e.g., algae ▪ **Land conservation** is a potential benefit with cultured meats and dairy produced with a much smaller land footprint than observed with the conventional agriculture ▪ **Biodiversity conservation** opportunities, such as rewilding of former agricultural land to enhance local ecosystems, reducing harvest of fish species at higher trophic levels or with biobanks of animal and plant cells and genetic material ▪ **Upcycling/waste management** opportunities involve using low-value input materials or waste from conventional agricultural production as inputs for cellular production that would otherwise go to landfills, supporting the creation of a circular economy

The final output was reviewed to identify major action areas for Canadian decision-makers. The review aimed to comprehensively cover the key priorities for addressing the multiple considerations for a domestic cellular agriculture industry (Table A5). In addition, the review aimed to develop recommendations that represent the key actions that most or all of our interview and focus group participants agreed upon and which were endorsed by the widest range of stakeholders possible. The major action areas include: **Develop a National Vision and Strategy for a Canadian Cellular Agriculture Industry in the Near Term; Establish a Clear and Transparent Regulatory Framework for Cellular Agriculture Products in Canada; and Provide Supporting Mechanisms for Research and Commercial Development.** In the case of the national strategy, this action area was found to be relevant in all emergent themes, as it will need to be developed with attention to the range of key considerations and many variables identified in this research.

Table A5. Action Areas for Cellular Agriculture in Canada and their Relevant Emergent Themes

Action area	Relevant themes
Develop a national strategy for cellular agriculture in Canada	Develop a National Vision; Government Incentivization; Economic Development Opportunity and Commercialization; Collaboration, Partnerships and Networks; Research, Technology and Innovation; Public and Industry Acceptance; Food Security and Health; Environment
Establish a clear and transparent regulatory framework for cellular agriculture products	Economic Development Opportunity and Commercialization; Collaboration, Partnerships and Networks; Research, Technology and Innovation; Public and Industry Acceptance
Provision of supporting mechanisms for research and commercial development	Government Incentivization; Economic Development Opportunity and Commercialization; Collaboration, Partnerships and Networks; Research, Technology and Innovation; Public and Industry Acceptance; Environment

In the section below, we have offered a broad narrative overview of the themes that were repeated most frequently during our stakeholder consultations and the points on which there was relatively broad agreement. While this overview does not capture all of the themes or positions that emerged from our consultations, it summarizes areas in which there is evidence of a dominant perspective. These themes, and the dominant perspectives that underpin them, determined our designation of priority action areas and informed the policy recommendations in this report.

Action Area 1: Develop a National Vision and Strategy for a Canadian Cellular Agriculture Industry in the Near Term

During our consultation process, all participants in our interview and focus group process agreed that cellular agriculture offers significant potential benefits and opportunities for Canada. The potential benefits cited were numerous and diverse and included a wide range of ways that cellular agriculture could advance food security goals, public health and nutrition, environmental sustainability, and economic development (see Table A4). It is important to acknowledge that all potential benefits are not mutually compatible and hence cannot all be realized. Therefore the majority of participants agreed that strategic national planning would either be necessary or advantageous to ensure that Canada is able to capitalize on the opportunities offered by cellular agriculture and to advance the widest possible range of economic, social, cultural, and/or environmental objectives as the industry develops.

A national vision for cellular agriculture should articulate a compelling value proposition to effectively build support for cellular agriculture and foster a strong Canadian cellular agriculture network. Successfully developing a cellular agriculture industry will require a systems approach that recognizes the relationships between different regions, sectors and stakeholders, and promotes cohesive and effective development of the industry. The rationale to develop a cellular agriculture industry should be based on Canada's unique advantages to ensure that Canada can carve its own leadership path within the broader industry. Successful strategies from other countries could be evaluated for potential alignment and implementation in Canada, such as Singapore's strong governmental support and incentivization, which has stimulated entrepreneurship, facilitated navigation of regulatory requirements, helped educate the public on novel foods and technologies and made Singapore a leader in this field. Public engagement, broad stakeholder consultation, and research into specific consumer preferences, wider public values and economic potential within Canada can be used to frame the value proposition for cellular agriculture and to determine the most crucial economic, social, cultural, and/or environmental objectives that should be placed at the centre of strategic planning. Key considerations, some of which are described below, include national and regional interests, collaboration and policy; strategic investment opportunities; communication and outreach; and economic opportunities and outcomes - including complementarity with conventional agriculture, integration into the existing food system, and job creation and employment opportunities. Regulation and mechanisms to support the cellular agriculture industry in Canada and are discussed separately below and are critical components in the development of the national vision and strategy.

The vision and support for cellular agriculture should be developed at the federal level but tailored toward the Canadian context in partnership with the provinces and territories, with strategic planning involving the identification of national and regional priorities and strengths. Canada has excellent research capacity and is home to globally top-rated universities (e.g., see www.cwur.org), as well as provincial and federal research institutes. Canada is geographically advantaged, has a strong food and agriculture sector with well-established supply chains, and opportunities exist for cellular agriculture to complement and integrate into these. Canada has existing strengths in agricultural production, a strong agricultural export

market, and numerous bilateral and multilateral free trade agreements (e.g., USMCA, CPTPP). Combined with a reputation for producing safe, high-quality food and agricultural products and access to feedstock, these national strengths could give Canada a strong competitive advantage in an emerging international market for cellular agriculture products. Building on these strengths would provide the opportunity for Canada to become a global leader in cellular agriculture while supporting domestic innovation, economic development and export opportunities. Involvement of provincial and territorial governments, as well as other regional stakeholders from the outset, will ensure that regional interests are considered, leverage existing regional strengths and build a cohesive cellular agriculture industry that meets diverse geographic needs and priorities. A mapping process to identify regions that would be particularly suited for certain aspects of the value chain could be a valuable exercise for the development of a national cellular agriculture strategy. Coordinating and leveraging regional strengths will present opportunities to build this industry across the country and will require federal, provincial and multi-provincial/territorial collaboration. Public policy will need to be developed in alignment with the national vision and will be essential for a coordinated and cohesive effort toward developing a strong domestic cellular agriculture industry.

Strategic public funding should be prioritized to support sustained large-scale investment, the construction of critical infrastructure, and the development of new regulatory frameworks. To justify the allocation of public funding and other necessary resources and to build public support for this new industry, a strong case needs to be made tying cellular agriculture to wider economic, environmental, social and/or ethical imperatives. A national strategy for cellular agriculture can be framed in the context of the overarching roadmap for the engineering biology space, with an opportunity for Canada to maximize return on investment by leveraging opportunities across various business verticals (e.g., cellular agriculture, advanced health biologics, and biomaterial production). Developing a national vision will largely demarcate the core benefits and opportunities that Canada should pursue through its support of cellular agriculture, and a comprehensive implementation plan will be essential to ensure that opportunities are successfully capitalized on. In addition to engagement with the conventional agriculture industry, public communication, awareness, and trust will be key. Communication strategies should present cellular agriculture primarily in terms of direct benefits (e.g., a new source of protein, products, diversification), and highlight synergies between cellular and conventional agriculture

Canada has a strong food and agriculture sector with a history of innovation and technology adoption, and defining the role of cellular agriculture in Canadian food systems will be critical to developing a national vision for the industry. Cellular agriculture will not be a substitute for traditional methods of agricultural production and existing food systems, but it can strengthen them by integrating innovative technologies and emerging production methods to reimagine a food system using all the tools, technologies, and methods available today. It also represents one of the few agricultural sectors that has the potential to create new markets and product categories, to provide more consumer choice, to diversify the food system, and to increase food security and supply chain resilience to external shocks (e.g., pandemics, climate change). Most stakeholders took the view that if Canada is not actively investing and playing in this space, we risk being left behind as other countries take the lead. However, it was noted by some that cellular agriculture may put traditional producers or conventional production methods at a disadvantage and that this would require careful management. A national cellular agriculture strategy should explore ways in which the cellular agriculture industry can work in collaboration with traditional producers and incorporate conventional farm outputs into cellular production methods. Business partnerships to procure feedstocks, license cell lines for cellular products, and explore methods of upcycling and monetizing agricultural by-products (e.g., starch, lignin, other) as inputs for cellular production will support the growth of the agriculture industry as a whole, as part of a sustainable and vibrant economic system. A strategic plan may also provide incentives to support conventional agricultural producers in developing products or technologies for the cellular agriculture sector. Further, food processors and manufacturers can be incentivized to develop products that incorporate both cellular agriculture ingredients and conventional farm ingredients, such as plant-based products that incorporate specific ingredients produced through cellular agriculture (e.g., heme or other ingredients to improve flavour, texture, or nutritional profile). Using engineering biology as a platform technology, potential also exists for employing the same tools to upcycle agriculture or other industrial by-products for cellular agriculture productions or to create non-edible materials and fertilizers. In addition to waste management, producing fertilizers through cellular agriculture-developed engineering biology tools can serve to strengthen relationships between the cellular and conventional agricultural industries.

Market opportunities presented through cellular agriculture have the ability to strengthen Canada's economy through diversification, and international markets will be important for the economic success of Canada's future cellular agriculture

industry. Canada is resource-rich and can build a cellular agriculture industry around a strong feedstock base. Canada's strong agriculture and agri-food export market can be capitalized on to grow the market by expanding the consumer base beyond the domestic population. As an early adopter of and leader in cellular agriculture, Canada would benefit from being a producer of a wide variety of protein products for both domestic and export markets. In contrast, if Canada does not become an earlier adopter or leader in this field by investing in the necessary research and infrastructure, the country's involvement in the global cellular agriculture market could be primarily as a feedstock supplier, thus limiting its ability to harness the vast economic diversification opportunities the emerging industry will provide. Strategic planning should also involve the identification of other industries (including those unrelated to food and agriculture) that could develop relationships with cellular agriculture producers or incorporate cellular technologies for additional economic growth.

Developing a cellular agriculture industry in Canada will create new employment opportunities, increasing the number of well-compensated positions for highly skilled workers. New start-ups are already entering the cellular agriculture space in Canada while existing businesses are exploring the use of cellular technologies to increase production and develop new products for domestic and export markets. While some stakeholders expressed concern that cellular agriculture could result in job displacement, it is highly unlikely that cellular agriculture can advance quickly enough to result in the displacement of existing workers. There may be a loss of overall livelihoods in certain traditional agricultural sectors, such as the animal agriculture industry, although this is significantly more likely to be subsumed within the wider dynamics of generational turnover than to be experienced as an abrupt displacement. Strategic planning could be used to locate cellular agriculture facilities in regions most likely to experience job displacement from the emerging industry, as well as in regions that are experiencing ongoing job displacement as a consequence of resource depletion, climate change, or other factors (e.g., a cellular seafood facility in a region economically dependent on fisheries). Workers in many other sectors, including those unrelated to agriculture or food production, will also have skills that are transferrable to cellular agriculture (e.g., in the oil and gas industries, industrial biotech and biomanufacturing, health). Facilities may be situated in regions where job losses are occurring in these sectors; where skill upgrading is needed, training programs or other strategic initiatives should be used to help transition workers into the cellular agriculture industry.

Beyond economic development and job creation benefits, cellular agriculture has the potential to support food security in Canada and enhance supply chain resilience. In order to contribute to food security in a meaningful way, cellular agriculture products must be affordable and widely accessible. It is anticipated that cellular agriculture will have the potential to develop less expensive sources of protein and, when produced at scale, could offer vital sources of macronutrients to individuals and populations that cannot afford a consistent supply of animal-based products or existing plant-based alternatives. This would provide valuable opportunities to reduce inequalities in the food systems, increasing nutrition and public health in communities throughout Canada and across the globe. However, such benefits will only be realized upon reducing production costs and parity with existing products. Affordability and accessibility are critical characteristics of food products that effectively contribute to food security. Canada must support efforts to decrease the cost of cellular agriculture products, including by investing in scale-up facilities and developing strategies to overcome other barriers to both market entry and consumer access. This will help reduce consumer barriers to purchasing foods perceived as culturally appropriate, ethical, and/or environmentally sustainable. When economically viable, the portability of cellular agriculture can contribute to the distribution of food production and create opportunities for both urban and potentially rural communities to reduce producer-consumer distances and decrease supply chain vulnerabilities, as well as diversify local economies.

Cellular agriculture can enhance supply chain resilience in Canada in multiple ways. A thriving and diverse domestic cellular agriculture industry could feed into existing or create additional supply chains, thereby increasing redundancy and creating resilience in the face of large-scale socioeconomic disturbances, climate change and shocks to food systems. Engaging large Canadian food processing and retail businesses in Canada's vision for a cellular agriculture industry would ensure that cellular products are integrated into established supply chains and distribution networks, as well as encourage private sector investment (from well-resourced companies) into a domestic industry. However, it is currently unclear what relationships cellular agriculture will ultimately develop within a supply chain (e.g., feedstock, consumer base, waste management, etc.), and potential new vulnerabilities will need to be considered and addressed. Life cycle analyses and techno-economic analyses are critical for understanding and improving cellular agriculture's potential for contributing to environmental sustainability in Canada and globally.

Action Area 2: Establish a Clear and Transparent Regulatory Framework for Cellular Agriculture Products in Canada
Throughout our interviews and focus groups, regulation was the most frequently cited potential barrier to developing a cellular agriculture industry in Canada and is a crucial element for the success of the emerging cellular agriculture industry in Canada. Potential regulatory barriers pose a serious threat to innovation, including the very real risk that delays in the regulatory approval process for new products could have damaging financial implications for start-ups. The perception of a regulatory system that is unsupportive of cellular agriculture could deter companies from entering Canada, incentivize start-ups to leave the country, and dissuade private investment in this sector. Participants indicated that regulatory pathways in Canada for this new industry are unclear, and potentially lengthy and expensive and that there is no indication of what labelling requirements might be imposed. Consequently, interview and focus group participants very frequently pointed to regulation as the single most important factor that would determine if Canada would be able to establish a successful cellular agriculture industry.

Regulatory requirements for cellular agriculture products should be developed early while also taking care to ensure that regulatory frameworks remain agile and sufficiently flexible to accommodate future cellular agriculture technologies or production methods not yet in development. Regulatory agencies should be involved in the development of a national strategy and at all stages of the planning process to ensure that cellular agriculture products encounter a smooth and transparent approval process when they are ready to enter the market. Planning for cellular agriculture should encompass all aspects of the regulatory process, including product classification, labelling and consumer marketing.

While there are concerns about the clarity of the regulatory process for cellular agriculture products, it should be noted that the Canadian food testing regulations and scientific product-based approval system already in place were perceived in a largely positive light by participants. Canada has an international reputation for excellent food safety, and this reputation is acknowledged as offering a competitive advantage as cellular agriculture products enter the global market. Consumer perception will be crucial to developing a domestic market for cellular agriculture products, and the rigorous food safety testing and nutritional analysis that products are required to undergo prior to entering the market was considered a positive feature that can be highlighted while developing communication and public outreach strategies. Providing consumers with choice, prioritizing the development of healthy and safe cellular agriculture products, and promoting health benefits (e.g., tailored nutrition and reduced allergenicity) would be valuable for increasing trust in the products and industry, and consumer perception of cellular agriculture should be addressed at all stages in the development of a Canadian industry. Perception will also likely vary with product type, with fermentation-produced products already on the market and possibly being more readily and easily accepted initially than cultured meat products. As such, there is a need for research into consumer risk perception, as well as the broader values underlying consumer preferences, to develop a relevant and coherent communication strategy around cellular agriculture. Consideration must be made of the range of consumers and stakeholders that must be communicated with, and the message has to be one that everyone can connect with. Unambiguous government support for cellular agriculture will help to build consumer confidence in these products, whereas delays in approving cellular agriculture products or confusion over government regulation may create concern or give the perception that cellular agriculture products are risky. Participants were overwhelmingly supportive of policies that ensure cellular agriculture products face the same high standards and rigorous analysis expected of all foods entering the Canadian market and of ensuring that these same standards are applied to foods produced for export, but that Canada needs to develop a clear regulatory pathway for cellular agriculture products to ensure a smooth entry into both Canadian and international markets, as well as an outreach and education strategy to relevant stakeholders and the general public.

Aligning with the issues discussed in this report, interview participants generally characterized the regulatory approval process as extremely time-consuming, unpredictable, and opaque. There was also some concern that the approval process could end up being even slower for products produced through cellular agriculture methods than for other novel foods, which is already seen as being slow enough to present a major barrier to innovation. As was pointed out, start-ups and small companies can burn through their capital and deplete their resources while waiting for regulatory approval, detrimentally affecting their viability if there are unexpected delays. It would be highly beneficial for the future development of the industry to ensure that these companies receive significant, targeted support in navigating the regulatory process. As part of a wider national cellular agriculture strategy, Canada should consider appointing industry liaisons or developing a government program with dedicated "concierges" to aid companies navigating the regulatory process, working with both applicants and regulators to expedite the approval process. Additionally, regulatory bodies should include experts on cellular agriculture and

the underlying technologies to provide the necessary knowledge and understanding needed to assess and approve these products. Creating a regulatory environment and framework in Canada that is friendly and attractive to cellular agriculture companies can enable innovation, entrepreneurship and stimulate growth in the industry while also meeting the rigour of the regulatory process and food safety that Canada is known for.

Transparent classification and labelling will have wider policy implications and influence strategic planning of the industry and is key to attracting and maintaining a consumer base for cellular agriculture as well as helping to minimize conflict with conventional agricultural producers. Products should be introduced into the market with clear communication about how they are made and names that are both descriptive in terms of communicating the nature of the product and appealing as food items, and in clear and relatable language (e.g., microbrewery-style production). A lack of clarity on labelling requirements could be a concern for both the conventional and cellular agriculture industries. Ensuring that cellular agriculture products are labelled and presented as distinct from animal-based products will avoid confusion and reduce opposition from livestock industries. However, for consumers, labelling requirements could contribute to the sense of unnaturalness because, unlike animal products, cellular agriculture labels could include a lengthy list of ingredients (e.g., rather than simply being labelled as "milk"), which would increase the appearance of artificialness even though the conventional product would have as many or more ingredients if it were labelled in the same way. As such, it is essential to develop labelling requirements that are clear for consumers yet do not disadvantage cellular agriculture products in the market, particularly in comparison with conventional analogues. It is also important to ensure that labelling does not put cellular products in a niche category or negatively influence store placement, which could harm consumer perception and have a knock-on effect of dissuading companies from establishing in Canada.

While regulatory frameworks present a challenge for cellular agriculture in Canada, they also present potential opportunities. At present, regulatory pathways in Canada are unclear; they may be time-consuming and expensive for this new industry, representing a real risk to commercialization and company viability. As a result, cellular agriculture companies could be more inclined to establish in jurisdictions with more clearly defined and easily navigable regulatory systems. There is an opportunity for government to examine models in leading countries for their regulatory approach, e.g., Singapore. Such an environment includes quick processes, clear guidelines and expert government consultants to provide guidance and help on steps for getting products to market. Canada also has an opportunity to develop engagement processes and consultations with regulators, industry, not-for-profits, and the public, and to develop clear regulatory pathways and innovative programs for supporting companies through the regulatory process. This could set Canada apart from other countries, potentially making it a desirable jurisdiction by overcoming the reasons it is currently perceived as risky. Canada could become a leader in this area and serve as a global model of effective cellular agriculture regulation, and this, along with other Canadian advantages, would enhance its reputation in the global market.

Action Area 3: Provide Supporting Mechanisms for Research and Commercial Development

Developing a cellular agriculture industry and achieving a leadership role will require substantial government incentivization through public funding, including direct investment in cellular agriculture research and development, necessary infrastructure, in-kind support, and the incentivization of private investment and strategic partnership development that furthers national priorities and advances public interests. All participants in our interviews and focus groups agreed that significant government incentivization was necessary to develop a successful cellular agriculture industry and, ideally, to position Canada as a global leader in this area. Participants were overwhelmingly positive that investment in this space would not only pay dividends in terms of economic development and job creation but also that this would support Canada to achieve wider social and/or environmental objectives. Not only will significant investment be vital to developing a successful cellular agriculture industry in Canada, but it will also be the clearest and strongest signal to companies, private investors and other stakeholders of government commitment to this endeavour.

Public funding and in-kind support must be substantial, not incremental, and sustained to drive the industry forward and for cellular agriculture to be a viable and competitive industry in Canada. Public investment should be increased throughout the pipeline to enable dedicated, industry-driven academic research, to allow start-ups to get up and running and later to diversify funds from private sources, incentivize shared IP generation where appropriate, provide pilot and scale-up facilities and support transitions from pre-commercialization to commercialization. Public funding can be used to attract matching

funds from industry, facilitate collaborative research and development, and incentivize private investment. Entrepreneurship is essential to the growth of the cellular agriculture industry, and Canada will need to adopt multiple strategies to stimulate entrepreneurship in this sector. Public funding throughout the pipeline would make the industry more attractive to potential entrepreneurs and increase interest in cellular agriculture among potential investors. Public in-kind support for the cellular agriculture industry, and entrepreneurs and start-ups, in particular, should include access to lab space and equipment and to key entities such as hubs, accelerators and incubators across the country to provide business support, the use of facilities and sharing of knowledge and research. Innovation hubs should be developed in a coordinated manner to provide opportunities nationwide and to stimulate entrepreneurship, and help break down the barriers to entry that are currently faced by cellular agriculture start-ups across the country. Developing these in concert with broader hubs would support start-ups as they transition to viable businesses. The hub-and-incubator system would need to include facilities (affordable lab space, scale-up, etc.), as well as access to expertise, mentorship, and investment opportunities. Support is also required to ensure that skilled HQP are trained in this area and retained in Canada, and increase awareness of the potential for cross-disciplinary expertise and attract qualified HQP from other industries.

To date, no dedicated public funds for this industry have been committed by governments at any level in Canada. Available grants from research funding agencies are dedicated to academic research, and cellular agriculture frequently falls outside of the funding focus areas (e.g., health, conventional agriculture). Grants and funding mechanisms also often do not accommodate the multidisciplinary teams essential for successful cellular agriculture research. The establishment of dedicated funding streams would enable both industry-driven and fundamental open research that is of paramount importance to drive widespread development in the commercial sector, as well as allowing novel products that are as yet unimagined to come to fruition.

To further support R&D within start-ups, the public sector and granting agencies should recognize that cellular agriculture in Canada is an entirely new industry, and start-ups working in this space are often pre-revenue with high operation and infrastructure costs, and limited opportunities to partner with larger companies until at a later stage. Cost-sharing programs and grants requiring matching funds or partnerships could create difficulties for young start-ups, and a dedicated granting program that considers these early-stage challenges would be invaluable for supporting innovation and competition within this emerging industry.

This public funding requirement is not unique to Canada, and the emergence of tools and technologies to grow the Canadian cellular agriculture industry is an opportunity for Canadian leadership. From a societal perspective, public funding could be connected with policies such as climate action and grand challenges to encourage the industry to grow through sustainable practices and innovations. Recent investments by risk-averse Canadian institutional investors, including Canadian Pension Plan Investment Board (CPPIB) into Perfect Day, and Motif FoodWorks by Ontario Teachers' Pension Plan Board, provide a solid endorsement for investments into the industry.

With a lack of public funding globally, private funding such as venture capital is the most common funding source for cellular agriculture worldwide, yet obtaining private investments can be difficult for early-stage businesses due to long return on investment periods for this industry. In addition, cellular agriculture research and development is expensive, and most start-ups in this space are pre-revenue. Capital expenditures for lab space and scale-up facilities are prohibitively expensive for individual companies, and private investment is expensive and frequently does not support construction of large-scale infrastructure. Private funding will continue to serve as an important support for cellular agriculture, and encouraging investment through mechanisms such as accelerator programs is valuable; however, moving the industry forward will require a diversification away from a primary reliance on private funds.

Fundamental and industry-driven research is essential to the development of cellular agriculture in Canada. Fundamental research in key areas, such as cell media or feedstock optimization, or tissue scaffolding, is essential to provide some basic building blocks for the developing industry. Industry-driven applied research is critical for accelerating the commercialization of products, and such work will facilitate movement in the Canadian cellular agriculture space to go beyond bench experiments and toward production at scale. There is a tremendous opportunity to grow the cellular agriculture industry and engineering biology capacity of Canada in parallel. Canada has strength and expertise in engineering biology that can be

leveraged, and these tools are fundamental to cellular agriculture production. Advancements made in this industry will be applicable to other industries and business verticals and vice versa, as engineering biology is a platform technology that can be applied across sectors and disciplines.

Industry-driven research could exist in the form of industry-academia or industry-industry partnerships. For the former, academic partnerships could be particularly useful for start-ups, as these companies would benefit from having access to research infrastructure (labs, scale-up) and skilled/specialized talent (e.g., research assistants, graduate students, post-doctoral researchers) to support their research and development activities. Industry-industry research partnerships are also valuable, including between start-ups and large corporates, as they encourage knowledge-sharing for spurring innovation, as well as enable research and development that allow different companies to focus on and specialize in different aspects of the value chain (e.g., growth media, front-end development, etc.). More broadly, regional, national, and international partnerships of industry, academic, government and non-governmental stakeholders are important to the development, advancement, and success of a cellular agriculture industry in Canada, breaking down silos with different expertise and know-how spread across a large geographic range. Regional partnerships are important for connecting start-ups with research infrastructure, academic and business expertise, and talent via networks developed through incubator/accelerator programs and industry-academia partnerships. Regional and national partnerships can also lead to fruitful B2B relationships. National and international partnerships are important for scaling up, accessing diverse funding sources and larger markets, and for knowledge sharing. Networks and consortia are also important components of the emerging cellular agriculture industry in Canada. Networks should include diverse fields of multi- and transdisciplinary expertise and platforms (e.g., omics, engineering biology, stem cells, tissue engineering, food sciences, artificial intelligence technologies, policy, social sciences) for interdisciplinary cross-pollination of ideas and to facilitate dialogue between disciplines, and could also drive engagement through innovative and effective education and outreach activities. There is a need for the parallel evolution of socioeconomic and cultural innovation along with technology innovation to ensure uptake of cellular agriculture products. Canadian researchers and industry stakeholders could benefit greatly from models/lessons provided by early adopters of and leaders in cellular agriculture technologies, such as Singapore, the United States, and Israel.

Infrastructure and pilot facilities should be a priority for public investments in cellular agriculture, particularly facilities for piloting and scaling up productions that start-ups can access and achieve scale-up past proof-of-concept production and enable next-round financing while recognizing the differing needs of various product types, the broader industry, the carbon source and stage in the innovation process. Consideration must be given to current infrastructure needs and future priorities, particularly with respect to scale-up, and instill flexibility in infrastructure capacity to address multiple business/sector opportunities, as well as considering how to effectively integrate cellular products into existing and established food systems and distribution networks. A significant, near-term investment in such infrastructure is required and would give Canada a leading opportunity to retain domestic companies, facilitate training of personnel, attract global investment and companies, and lead in this industry and field of technology, thereby leading to substantial return on investment. Examining recent Canadian investments in plant-protein innovation and processing in the prairies, as well as in other areas such as vaccine biomanufacturing infrastructure, could provide models and blueprints that could be applied to stimulate growth in the cellular agriculture industry.

Specialization of start-ups and B2B companies could allow for more rapid development of a cellular agriculture industry in Canada. Recognizing that B2B companies will be a fast-growing and lucrative sector as the industry matures, encouraging specialization will allow companies, players, and regions to improve practices and target/solve challenging problems at specific stages of the value chain (cell media, front-end development, large-scale production, or other aspects of cellular agriculture production). It is important to recognize that financial limitations of start-ups and young companies create an environment in which it is prudent to focus on, specialize in and supply one part of the chain, and, unlike the first wave of cellular agriculture start-ups, fewer companies going forward will be fully verticalized (i.e., everything done in-house, from media or feedstock development to producing the finished product). Changes in investment or innovation policies in Canada to encourage entrepreneurs, networks and partnerships will offer opportunities for B2B and other companies through an ecosystem approach along the value chain.

Talent pipeline considerations are important and must address the fact that cellular agriculture is a complex field that exists at the intersection of multiple disciplines, requiring both diverse and specialized knowledge, as well as cross-sectoral expertise. Attracting and retaining companies and talent operating in the field of cellular agriculture (or related fields) is essential for any country aiming to develop a domestic industry. Training and expertise in cellular agriculture are essential for establishing and growing companies. However, given the current lack of specific cellular agriculture training opportunities in Canada, consideration is needed to attract, encourage, and train qualified people with the necessary range of experience and knowledge in biomanufacturing to this new and emerging opportunity. It will be critical to increase awareness and attract talent from other relevant sectors into this space, such as process engineers, chemical engineers, fermentation expertise, stem cells, others etc., as well as the potential to repatriate/re-train talent from other sectors, e.g., oil and gas, for this field. It is necessary to facilitate training in different disciplines as cross-sectoral expertise is essential, and future training programs for cellular agriculture should prioritize these opportunities.

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(Box 1)

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Acknowledgments

Funded by Ontario Genomics and Agriculture & Agri-Food Canada (AAFC), this strategic initiative was led by Ontario Genomics in partnership with the National Engineering Biology Steering Committee, the Food & Agriculture Institute (FAI) at the University of the Fraser Valley, and Dr. Michael von Massow, University of Guelph.

We would especially like to thank the members of the National Engineering Biology Steering Committee's Food Security Subcommittee for their valuable insight and involvement throughout the consultation process, as well as the continued support of other members of the National Engineering Biology Steering Committee.

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We thank the following individuals and organizations for offering invaluable insights and discussing viewpoints around cellular agriculture and the challenges and opportunities of integrating this emerging industry into Canadian food systems during our consultation process:

Agriculture and Agri-Food Canada (AAFC)
Murray McCaig, ArcTern Ventures
Pratish Gawand, Ardra Bio
Andrew Powell, Asia Biobusiness Pte. Ltd.
Ralph Christian Delos Santos, Biofect Innovations
Andy Stone, Canada's Oceans Supercluster
Amie Peck, Canadian Cattlemen's Association
John Jamieson, Canadian Centre for Food Integrity
Caitlin Walsh, Canadian Pension Plan Investment Board (CPPIB, Thematic Investing)
Caroline Lester, Canadian Pension Plan Investment Board (CPPIB, Thematic Investing)
Ahmed Khan, Cell Agri & Cellular Agriculture Canada
Bobby Matheson, Dairy Farmers of Canada
Matt Morrison, Dairy Farmers of Canada
Kamil Drapala, FairLife
Lejjy Gafour, Future Fields
Miranda Stahn, Genome Alberta
Richard Donald, Genome Atlantic
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Krishna Mahadevan, University of Toronto
Justin Kolbeck, Wildtype Foods

Thanks to our partners, Lenore Newman, Rob Newell and Kate Newman from the Food and Agriculture Institute (FAI), University of the Fraser Valley for their work during the consultation process, and assistance in preparation of the report and consultation summary; and Michael von Massow for his economic analysis that contextualizes the magnitude of the economic opportunity for cellular agriculture products in the Canadian food system.

We would like to acknowledge Agriculture and Agri-Food Canada for their support of this project.

We also thank the many Ontario Genomics colleagues who made this report possible. In particular, Elaine Corbett and Laura Riley who led this strategic initiative and the writing of this report, as well as others on the Ontario Genomics team including Jordan Thomson, Helen Petropoulos, Polina Martins, Zoya Retiwalla, Camilo Acero, Koula Ferreira, Stephanie Marquez and Bettina Hamelin. Special thanks to Kaitlyn Lemay.

We are grateful to the following stakeholders for their contributions to this report: Evan Fraser for his help during the consultation process, and Cellular Agriculture Canada volunteers Avery Parkinson, Francesco Zangari, Reuben Blaff.

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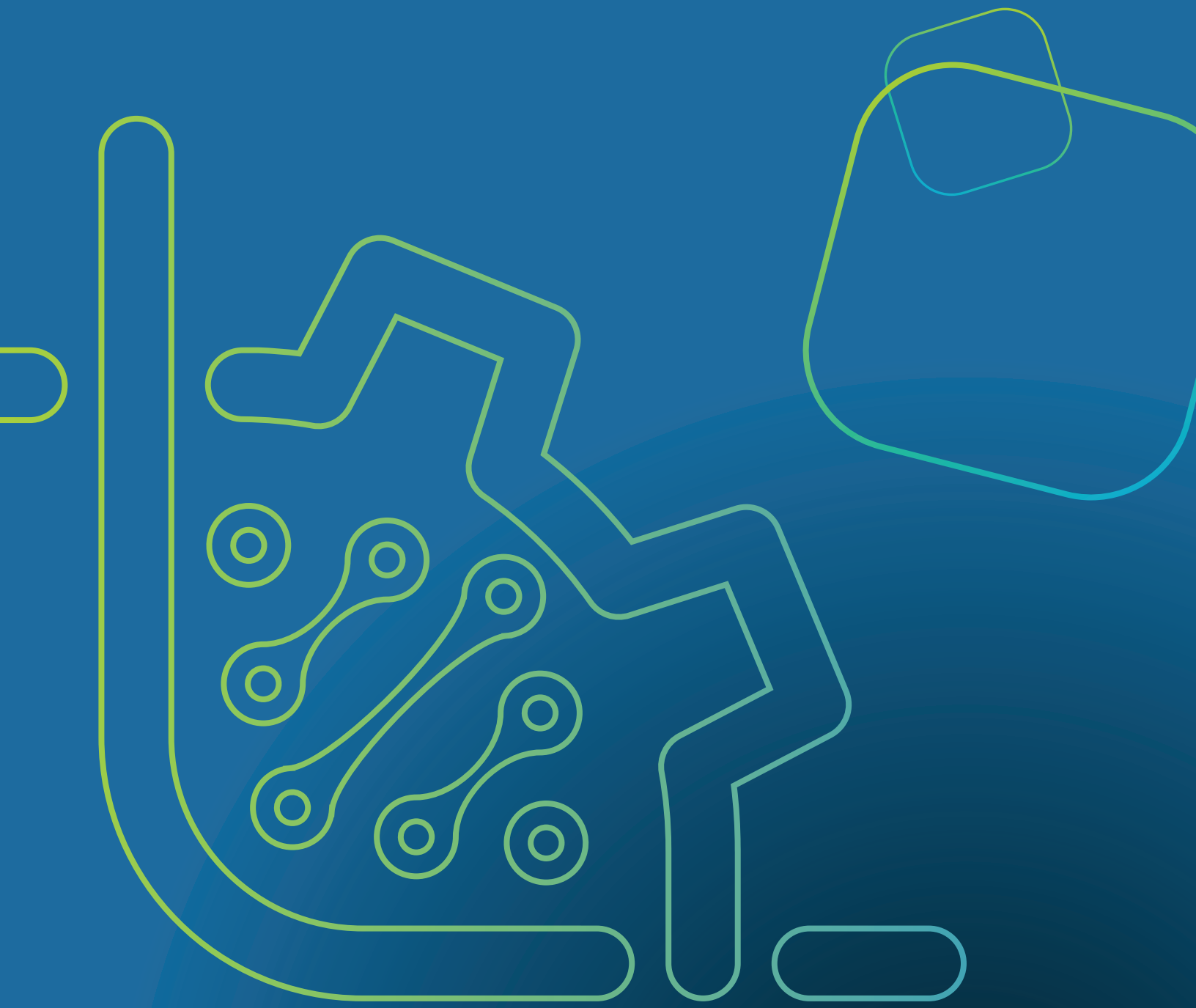

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