Cellular Agriculture Australia

White Paper

Cellular Agriculture

An Opportunity to Diversify Australia's Food System

Executive Summary

Cellular agriculture involves the production of animal-derived products using cell-based biotechnologies instead of animals.

It creates a powerful new opportunity for Australia to diversify our food production, strengthen food security and seize a greater share of the growing global demand for protein, anticipated to reach 872 million metric tonnes (~USD$2,636B) by 2035[1]. For Australia, the sector could deliver significant economic returns by creating highly skilled jobs, deepening our research and advanced manufacturing capabilities, and expanding trade across the Asia Pacific region. As a food production technology that is largely independent from environmental conditions, cellular agriculture also offers a compelling opportunity to diversify Australia's agriculture sector as drought and other climate changes pose mounting challenges to conventional food production.

Cellular agriculture is an emerging global industry. Since 2015, over 90 cellular agriculture companies have been founded worldwide[2]. The first cultivated meat product was approved for sale in Singapore in 2020[3], and USD$1.2B was invested in cultivated foods globally in 2021[4].

With world-leading agriculture and biotechnology research sectors, and developing advanced manufacturing infrastructure, Australia is well positioned to become a global leader in cellular agriculture. However, research and commercialisation in this exciting field is in an early phase in Australia compared to other fast-growing industries (such as renewable energy and autonomous vehicles) and there is little public investment in the Australian sector[5,6].

__Inside front cover:__ Cultivated Nigiri Salmon by Wildtype

Cellular Agriculture Australia has developed three recommendations for public investment and infrastructure development to advance cellular agriculture in Australia and address existing barriers to growth:

1. **Developing a skilled and future-fit workforce to enable commercialisation and industry growth**
2. **Deepening Australia's cross-disciplinary open access cellular agriculture research**
3. **Establishing at-scale manufacturing capabilities and infrastructure**

Together, these recommended strategic public investments in the cellular agriculture industry can reduce economic, environmental, health, and ethical costs in our animal agricultural system and ensure Australian competitiveness in a growing global market for meat and other animal products.

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Design work by Mouse & Mind.

Background

Cellular Agriculture Australia (CAA) was founded in early 2020 by cell biologist Dr Bianca Lê. We are a registered Australian charity focused on enabling the future of cellular agriculture in Australia through awareness, education and research.

CAA exists to support all stakeholders engaged in the sector: students, researchers, industry leaders, government, and future consumers. CAA is focussed on:

1. nurturing a diverse and future-fit pipeline of talent and research capability into Australia's cellular agriculture workforce;
2. advocating on behalf of the cellular agriculture sector to enable and support its future growth and impact; and
3. providing an objective evidence-based voice to raise awareness about the sector and its potential for Australia.

Our work is entirely funded by philanthropy.

Contents

Chapter 01

1.1 What is cellular agriculture: The 101

Cellular agriculture is a suite of technologies that enable the production of animal-derived products using cells instead of the animals themselves. There are two distinct categories of cellular agriculture technology (**Figure 1**):

- **A** Cell cultivation (cultivated meat): involves the production of muscle and fat (for meat), skin (for leather or food) and liver (for foie gras) from stem cells isolated from an animal. This technology is well researched for regenerative medicine applications (tissue engineering) but has not yet been applied at scale for commercial food production in Australia.
- **B** Precision fermentation: involves engineering microbial cells (yeast, bacteria or fungi) to produce animal ingredients such as egg or milk fats and proteins. This technology has already achieved widespread application in the production of other animal-replacement products, such as insulin and the cheese-making enzyme, rennet.

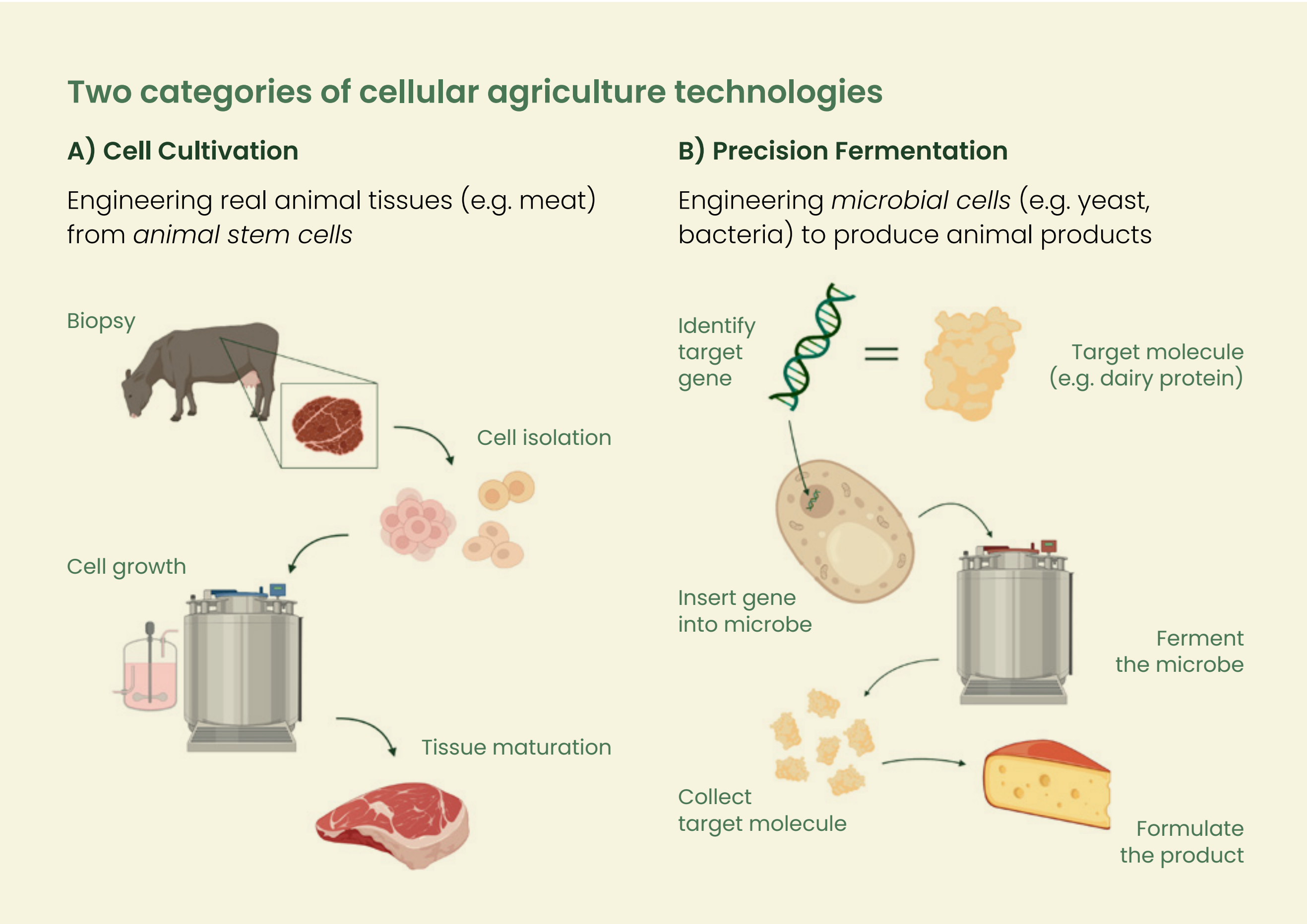


Figure 1: Cellular agriculture technologies are classified in two categories: A) Cell cultivation (cultivated meat) and B) Precision fermentation. *Graphics created with biorender.com*

Alternative proteins (to traditional meat, seafood, eggs and dairy) are the most common applications of cellular agriculture. However, cellular agriculture can also produce a range of traditionally animal-derived ingredients and supplements, food processing enzymes, and biomaterials (e.g. leather, fibre, silk and fur). Ingredients made using cellular agriculture technology, such as animal fats and oils, are also increasingly being added to "hybrid" food products (i.e. foods that incorporate plants and cellular agriculture ingredients such as animal cells, fats or proteins) to enhance the taste, texture and cooking performance of products. In this paper, we detail the benefits and barriers in the growth of cellular agriculture technology specific to sustainable food production in Australia.

Above: *University of Melbourne PhD researcher Brodie Peace*

1.2 What is the vision for cellular agriculture in Australia?

Animal products play a major role in Australian diets and those of many around the world. Australians consume an average of 89 kg of meat per capita each year[7]. This is the world's third highest per capita rate (behind the US and Israel), and significantly higher than the OECD average of 70kg/capita[7]. On the global stage, animal products are Australia's seventh largest goods and services export. They generated AUD$14.6B in 2018-2019 and are key in our relationship with strategic partners such as Indonesia and Japan[8].

As the world's population continues to grow, so too will the need for protein. Global protein consumption is projected to increase from around 630 million metric tonnes in 2022 to over 870 million metric tonnes by 2035[1]. Available protein sources will be outstripped by growing demand, as there is simply not enough land available worldwide to sustainably meet future protein needs.

Cellular agriculture offers a way to diversify our food production to address food security challenges and maintain global competitiveness in new protein markets, where demand continues to grow strongly. Australia is well placed to capitalise on this growth by leveraging our internationally renowned expertise in tissue engineering and food science research, and the agricultural and advanced manufacturing industries[9].

Australia's nascent cellular agriculture sector is led by emerging companies, private investors and researchers at Australia's leading universities including Monash, Melbourne, UNSW, QUT and the University of the Sunshine Coast. Since 2018, eight cellular agriculture companies have been created here — All G Foods, Change Foods, Eden Brew, Hueros, Magic Valley, MeAnd Food Tech, Nourish Ingredients and Vow (**Figure 2**). Two hardware manufacturing companies have also expanded into the development of bioreactors for cellular agriculture food production: Sartorius and Agritechnology (**Figure 2**).

The Cellular Agriculture Ecosystem in Australia | June 2022

Cultivated meat and seafood

- VIC: Magic Valley
- NSW: Vow
- Shiok Meats – Seafood, reinvented

Breastmilk

- VIC: me&

Animal free dairy

- QLD/USA: change FOODS
- NSW: all g foods
- NSW: Eden Brew

Ingredients

- ACT: nourish INGREDIENTS

Manufacturing hardware

- NSW: Agritechnology
- VIC: Sartorius

Culture media

- QLD: HEUROS

Investors

- Better Bite ventures
- Square Peg
- 1123
- Blackbird
- tenacious ventures
- GROK VENTURES
- MAIN SEQUENCE – CSIRO Innovation Fund
- cefc
- GiantLeap

Accelerators

- Startmate
- Startupbootcamp

Nonprofits

- Cellular Agriculture Australia
- FOOD FRONTIER

Universities

- MONASH University
- UniSC
- The University of Sydney
- UNSW Sydney
- The University of Melbourne
- UTS
- QUT Queensland University of Technology
- The University of Queensland Australia
- Macquarie University Sydney·Australia

Figure 2: The cellular agriculture ecosystem in Australia

1.3 Highlighting the economic potential of cellular agriculture

CSIRO estimates precision fermentation could generate direct revenue for Australia of A$374 million to A$1.1 billion and create up to 2,020 jobs by 2030[10]. McKinsey predicts global sales of cultivated meat could reach A$26 billion by 2030[11]. There are currently around 200 skilled roles in cellular agriculture across Australia's private sector.

Modelling by CAA highlights the base case market size for Australian cellular agriculture food products is expected to reach AUD$105-210m by 2035, and could reach as much as $2.3b (See **Figure 3**)[7,12,13]. For this to eventuate, the sector needs to be supported by significant public investment and collaboration across new and existing value chains, in addition to the continuation of private funding.

In 2021, capital of AUD$44M flowed into Australia's cellular agriculture companies from reputable investors including CSIRO's Main Sequence Ventures, Blackbird Ventures, and the Clean Energy Finance Corporation. Over USD$1.B was invested in the global cultivated meat industry in 2021[4].

Over the next ten years, the sector is expected to grow rapidly, as the technology and regulation of cellular agriculture in Australia and around the world matures. At the time of writing, Singapore remains the only country in the world to give regulatory approval for the commercial sale of a cultivated meat product[3]. While the regulatory pathway for cellular agriculture products in Australia is not explored in detail in this report, Food Standards Australia and New Zealand (FSANZ) has noted the Food Regulation System in Australia and New Zealand is already equipped to deal with new types of foods, including foods produced by new technologies such as cellular agriculture[14]. By 2030, more private companies are anticipated to scale production to a commercial level, significantly expanding the potential market.

Potential market for Australian cellular agriculture products in 2035

Cellular agriculture market

$105-210m
Base case

Assumes

- Australia 1% of global meat production
- 11% alt protein adoption rate by 2035
- 6-12% of alt protein as cell ag
- AU$4/kg for cell ag products

$2.3bn
Most optimistic case

Assumes

- Australia 5% of global meat production
- 16% alt protein adoption rate by 2035
- 20% of alt protein as cell ag
- AU$4/kg for cell ag products

Overall synthetic biology

$1.9bn
CSIRO[15]

In food and agriculture, includes

- Biomanufacturing sustainable alternatives to animal proteins
- Engineered crops for improved resilience and nutrition
- Biosensors for security and surveillance of ag conditions ag products

Figure 3: Australia's cellular agriculture market is expected to reach AUD$105-210M by 2035

Note on methodology

Modelling for cellular agriculture market sizing is difficult given the sector's age and stage and the inherent number of unknown variables. This market sizing has been derived using data and forecasts from the OECD on global beef, pork, sheep and poultry consumption. Australia currently produces 1-5% of the world's supply of these meats[16,17,18]. In line with a variety of industry commentators, the forecasts in this report assume 11-16% penetration of alternative protein into the global market for these meats by 2035, 6-20% of which is attributable to cellular agriculture[19]. Finally, an assumed price of ~AUD$4/kg, based on various industry reports was used to derive the estimated market value for Australian cellular agriculture[19,20,21,22].

1.4 Building a sustainable food system for our country, people, and animals

The benefits of cellular agriculture go far beyond economics, with the discipline expected to play a critical role in the development of a resilient and sustainable food supply network.

A thriving cellular agriculture sector could contribute to addressing at least seven of the United Nations Sustainable Development Goals (SDGs) (**Figure 4**).

Food security

2 ZERO HUNGER
14 LIFE BELOW WATER

Scale production to match demand without additional land or water use, and increase resilience to natural disasters like floods, drought, and bushfires.

Export of scalable, diversified types of protein secures regional food security and deepens Australia's reputation as a provider of safe and high-quality protein.

Climate

12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND

Preliminary life-cycle assessments showed that cultivated meat could result in a reduction of up to 92% of greenhouse gas emissions, 63-95% of land use, and 82-96% of water requirements, compared to conventional meat production[24].

Scientific advancement

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Breakthroughs in cutting-edge life sciences embed Australia's leadership as one of the world's top 10 contributors to life sciences research[23].

Foundational skill sets in cellular agriculture can be translated to other industries (e.g. tissue engineering in regenerative medicine).

Health

3 GOOD HEALTH AND WELL-BEING

Human health risks are minimised, with a lower likelihood of pathogen (e.g. Salmonella, E. coli) or faecal contamination, reduced odds of zoonotic outbreaks (e.g. swine or avian flu) and antibiotic resistance.

Animal welfare

3 GOOD HEALTH AND WELL-BEING
12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Animal suffering and slaughter are reduced.

Figure 4: Benefits of cellular agriculture stretch beyond the economic, with cellular agriculture potentially directly addressing seven of the United Nations Sustainable Development Goals.

Chapter 02

2.1 What challenges face the sector in Australia?

While there is an emerging cellular agriculture sector in Australia, it is still in a fledgling stage. Just six Australian academic labs are currently working on cellular agriculture research and eight Australian start-ups are working to produce cellular agriculture products and ingredients (**Figure 2**).

Research and discussions with industry and academic stakeholders identify three barriers to growth in the sector:

1. **Difficulty in sourcing local talent with cellular agriculture expertise, which is expected to increase significantly as the industry looks to commercialise and scale**
2. **Minimal funding for fundamental (early stage) cellular agriculture research, which typically requires more speculative and/or publicly funded investment; and**
3. **Lack of accessible, publicly funded infrastructure, which limits essential pre-competitive research and scale-up of manufacturing.**

The success of global industry leader, Singapore, has been built on the strong foundations of dedicated, government-funded academic research. As a country that is heavily reliant on food imports and vulnerable to supply chain disruptions, cellular agriculture is a logical part of the Singaporean government's '30 by 30' plan (to produce 30% of its nutritional needs locally and sustainably by 2030).

This is reflected in the country's growing investment in developing local talent through its universities (National University of Singapore and Nanyang Technological University both offer alternative protein-focused university courses), encouraging start-up growth through early-stage research funding (government research agency, A*STAR, offers funding grants of up to S$16M for alternative protein research) and incentivising global investors and companies to establish themselves in the country. Singapore was also the first country to legislate the sale of cultivated meat, which helped to attract industry leaders such as Eat Just's Good Meat[3] and Perfect Day[25] to establish facilities there. The nation is also home to several globally successful start-ups born out of university research, most notably Shiok Meats[26].

Above: *Morsel Malaysian Laksa by Vow*

Chapter 03

3.1 What can be done to address these challenges?

To drive the development of the sector, the Australian cellular agriculture sector needs strategic investment from the public sector, private markets, and dedicated education and research programs in three areas:

Pillar 1

Developing a skilled and future-fit workforce to enable commercialisation and industry growth

Pillar 2

Deepening Australia's cross-disciplinary open access cellular agriculture research

Pillar 3

Establishing at-scale manufacturing capabilities and infrastructure

Above: *Vow R&D Lab*

Pillar 1

Developing a skilled and future fit workforce to enable commercialisation and industry growth

Australia already has numerous world-leading tertiary education programs in the related fields of tissue engineering and precision fermentation. The Australian Regenerative Medicine Institute (Monash University) and the Centre of Muscle Research (University of Melbourne) are examples of centres offering relevant training in tissue engineering. Two institutions with programs involving precision fermentation are the Queensland University of Technology and the University of Queensland.

Through investment in the development of broad-based future skills, Australia can grow a pipeline of talent to support the commercialisation of these emerging technologies and cellular agriculture products. Investment in these skills would effectively bridge the gap in specialised knowledge required in cellular agriculture as well as supporting other technologies in the medical technology or agricultural industries.

Australian cellular agriculture start-ups each adopt their own unique technologies and processes, currently centred around tissue engineering for cultivated meat or synthetic biology for precision fermentation. These will soon require bioprocessing and advanced manufacturing expertise to begin scaling up manufacturing. The challenges in sourcing talent are varied, based on the technology and the start-up size.

Companies producing cultivated meat can draw on Australia's world-leading and globally competitive academic programs in cell biology and tissue engineering. Experienced professionals and researchers from these fields have been able adapt their skills and expertise effectively to the production of cultivated meat, which is what we have seen to date in the handful of existing Australian start-ups. There are however a limited number of senior researchers across the current Australian academic landscape and only a proportion of those will be able or have the inclination to transition into a start-up environment. Furthermore, the need exists for a volume of skilled talent spanning all levels of seniority and experience. However, there is a significant difference in the capability set required to develop product prototypes and samples compared to those required to design and implement pilot or commercial scale production facilities. This highlights the need for future-oriented, bespoke and cross-disciplinary subjects that could be offered across a number of Science, Technology, Engineering and Mathematics (STEM) courses that have a foundation in cellular agriculture. In addition to cell biologists and food scientists experienced in livestock/aquatic applications, there needs to be a particular focus on bioprocessing and advanced manufacturing to support the transition to scale across the entire production process of cultivated meat.

Companies using precision fermentation require synthetic biology skills in genetically modifying yeast and other microbial cells. Synthetic biology is an emerging field in Australia, and although start-ups in this space appear more advanced than cultivated meat equivalents, they are still in the early stages, with most currently having headcounts below 25. The size and relative cash position of precision fermentation start-ups leads to challenges in securing time and resources to support in training of generic-skilled synthetic biologists, requiring Australian start-ups to look overseas to source the required expertise.

The Australian cellular agriculture sector seeks to raise awareness of these technologies in key courses such as biomedical engineering, food science, agricultural science, and synthetic biology. This could encourage students to follow a pathway that enables them to enter the cellular agriculture field with the required technical skills and support the commercial growth of cellular agriculture.

Above: *Cultivated Shrimp dumplings by Shiok Meats*

This also enables the cellular agriculture sector to engage students across the globe who are increasingly seeking opportunities to learn about innovative technologies that can address major challenges related to climate change, food insecurity, and biodiversity loss.

Establishing a short course at or across key universities, which can be set up quickly and piloted with minimal cost, is an obvious first step. At Hebrew University, a short course in cellular agriculture was able to capture student interest and provide guidance on entering the field. **See GFI course at Hebrew university case study.**

From here, universities will need to develop an undergraduate subject in synthetic biology relevant to food applications, livestock-relevant cellular biology subjects, and biomedical or other engineering subjects focused on developing the required skills to design large scale bioprocesses and required manufacturing. The timeframes associated may be too long to avoid a shortfall in talent based on the pace of the industry and as a result alternative training and education pathways may need to be explored. This will ensure that students at all levels (undergraduate, honours or PhD) and transitioning professionals have pathways to develop the skills required to enter the cellular agricultural industry, with the relevant technical expertise and networking opportunities.

As the industry matures, Vocational Education and Training (VET) programs that train the labour workforce to work in cellular agriculture factories will become increasingly important. Practical skills such as the production and maintenance of cellular agriculture bioreactors, harvesting of food-grade cells and fermentation-derived ingredients, and quality assurance of cellular agriculture. Irrespective of the type of education provider, industry has a critical role to play in shaping curriculum content to ensure students graduate with relevant and applicable skills they can then apply to the field.

Case Study:
GFI course at Hebrew University

A short course established by the Good Food Institute (GFI) at Hebrew University in Israel demonstrates how cellular agriculture education can raise student awareness, which is often met with strong interest in further study or research work within the field.

In 2018, GFI representatives approached the university about piloting a cellular agriculture short course. Hebrew University expressed interest, and in 2019 the course was first offered to undergraduate students. GFI initially funded, prepared, and delivered the course, which was open to third year science students for credit.

The course provided students with an overview of the science and technologies underpinning cellular agriculture, and the broader sector ecosystem. Lectures from academic researchers and industry players focused primarily on cultivated meat, as well as some content on plant-based meat, precision fermentation and entrepreneurship. Importantly, the course supported students to develop a proposal for a potential cellular agriculture research project. Several proposals were then used in the following year for a postgraduate research thesis.

The course has rapidly expanded, with overwhelming student interest. In 2019, it started with 60 undergraduate students, far exceeding the usual course size of 10-15. The following year, it was expanded to postgraduate students.

The course was also offered at two other Israeli universities. Student surveys have consistently shown >70% satisfaction after completing the course.

In 2021, the three Israeli universities now support and deliver the short course themselves. The offering has also been expanded further to a short course for food scientists, specifically designed to help them pivot into alternative protein, demonstrating how education can also support incumbent industries and careers to transition.

GFI's work with Hebrew University illustrates how cellular agriculture education was able to capture student interest and provide guidance on entering the field. This is critical for building the talent pipeline and supporting research to keep advancing this growing sector. A key output from the implementation of these courses is the development of a free repository of curriculum materials that can be used to easily build new courses and learning modules around the world[27].

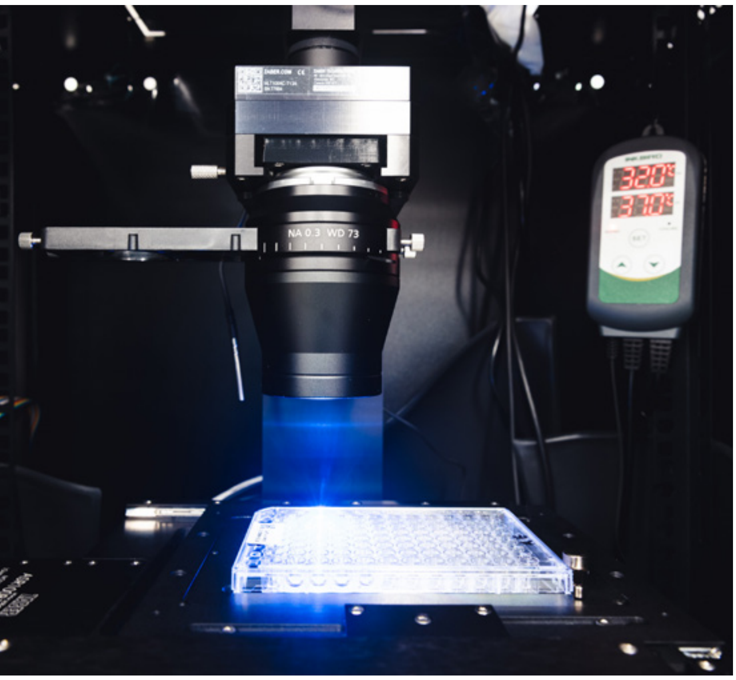
Similar courses could be taught in bespoke standalone VET programs or embedded in existing programs that serve adjacent food and agricultural industries. Developing globally competitive Certificate and Diploma programs for cellular agriculture manufacturing is key to scale production, reduce costs, ensure resilience, and improve product quality.

Pillar 2

Deepening Australia's cross-disciplinary open access cellular agriculture research

High-risk, pre-competitive, and multidisciplinary R&D is key to the cellular agriculture sector overcoming its barriers to growth and widespread adoption. Such research typically requires strategic public investment.

While private investment in cellular agriculture technologies has rapidly grown over the past three years globally, driving major technological innovations, public research in the sector is disproportionately underfunded. As a result, scientific discoveries and breakthroughs are locked up in incumbent private companies, which widens the so-called "valley of death" between basic research and research translation for product commercialisation (See **Figure 5**). This makes it increasingly difficult for new start-ups to enter the sector and, paradoxically, hinders innovation. In addition, the lack of objective academics and rigorous peer-reviewed research in these new technologies makes it more difficult to build consumer trust.



Above: *Automation technology at Vow*

Though the number of research projects advancing cellular agriculture science has increased in recent years, particularly in the U.S., Singapore, and Israel, this research has been conducted in a largely disjointed manner, with few centralised hubs for coordination. The field would benefit from dedicated interdisciplinary research centres to drive the science and technology needed to address the identified challenges of scaling cellular agriculture and supporting its commercial viability. These research centres would need to bring together researchers and industry partners to tackle the complex and common questions facing emerging fields like cellular agriculture. This approach would need to include fundamental scientific research, as well as adjacent topics such as food safety in cellular agriculture, Australian-specific regulation, and consumer studies involving acceptance and willingness to purchase.

Collaborative and cross-disciplinary research centres convene stakeholders from all disciplines necessary to the alternative protein field, and train scientists and engineers who will build the alternative protein industry. Advisory conditions can be implemented to ensure all training and research activities carried out by the centre will be suitable for commercial deployment to advance alternative protein production.

While many models of research centres have been pioneered, successful R&D centres universally require on-campus champions, clarity and alignment on their scope and purpose, early engagement with the right strategic partners, and sustainable sources of funding.

Recent examples include the National Science Foundation (NSF) granting USD$3.55M to UC Davis in 2020[28] and the U.S. Department of Agriculture (USDA) granting USD$10M to Tufts University in 2021 for the world's first National Institute for Cellular Agriculture, a flagship American cultivated protein research centre of excellence[29].

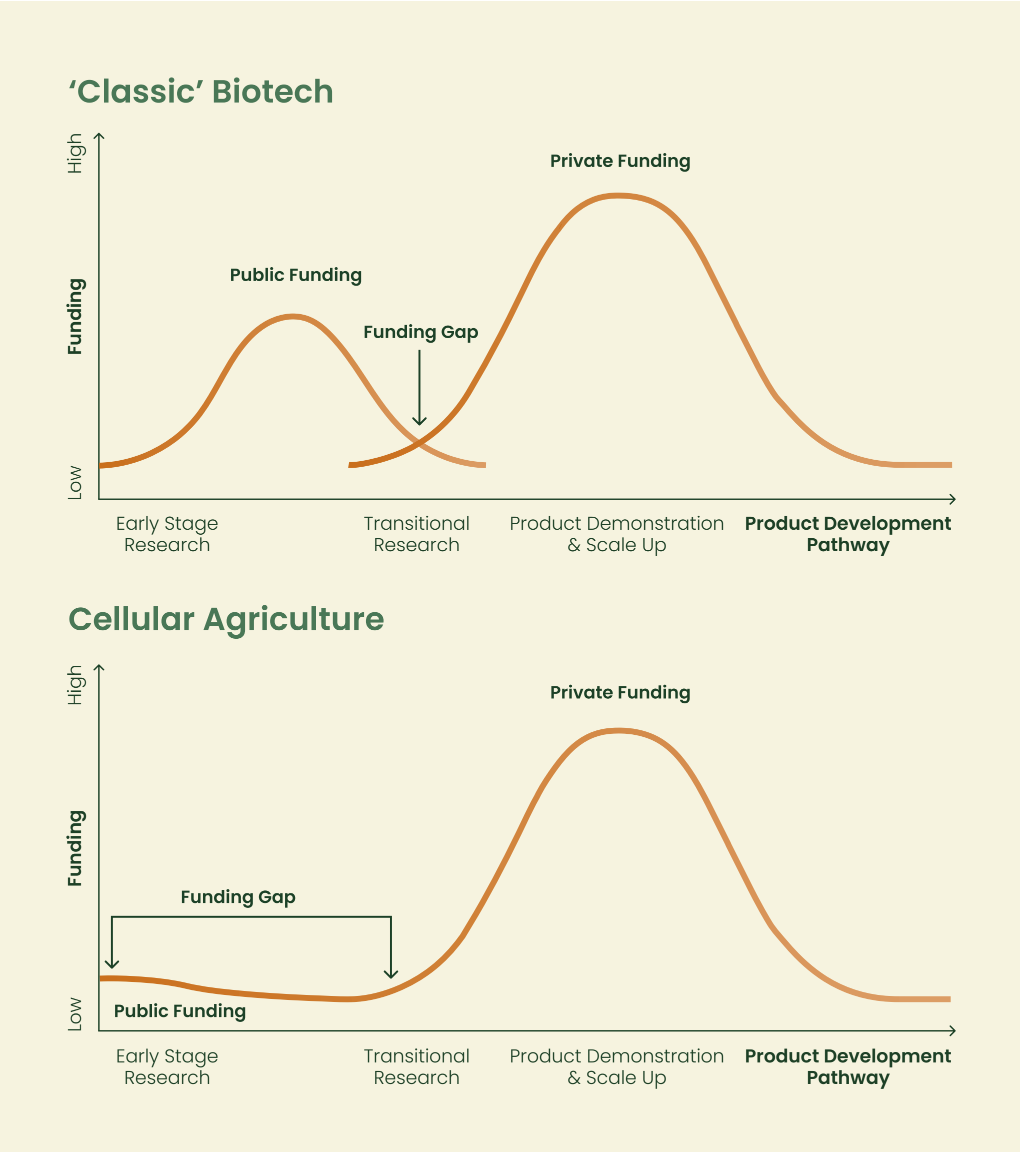


Figure 5: 'Classic' biotech and cellular agriculture funding gaps[30]

These Centres of Excellence allow researchers from across disciplines, schools, and campuses to collaborate on important questions and ideas relating to cellular agriculture.

A similar model in Australia could help elevate our universities as leaders within the alternative protein field, attract exceptional faculty and graduate students, train the next generation of leaders to power our global food supply, and strengthen the reputation of our universities as academic authorities.

Existing schemes such as the Australian Research Council's (ARC) Centres of Excellence program and the Cooperative Research Centres Program are ideal models of interdisciplinary and intersectoral research funding that are appropriate for the current pre-competitive stage of the cellular agriculture industry.

By including industry and end-users in the conception and design of these research centres, research findings can rapidly translate into commercial significance for the cellular agriculture sector to make significant real-world impact.

Pillar 3

Establishing at-scale manufacturing capabilities and infrastructure

Publicly funded and accessible infrastructure to support research and development is a key requirement to advance the cellular agriculture sector in Australia.

Based on our consultations with industry, the key immediate infrastructure required to develop, prototype and scale the manufacture of cultivated meat and precision fermentation products includes cell line repositories, scaffold databases, scale-up demonstration facilities and at-scale manufacturing plants.

- Cell line repositories are cold storage facilities (most likely -80°C and liquid nitrogen) that store cells from animals for human consumption, like cows or pigs. There are few existing food-related cell lines for cellular agriculture researchers to work with, as most cell culture work has focused on other species, such as humans, mice and hamsters. In addition, existing cell lines are often proprietary and difficult to obtain, creating a high barrier to entry for new firms and academic researchers. This challenge will continue to grow as more researchers, laboratories, and firms become interested in working on the development of cultivated meats. One example of a national cell line repository is CellBank Australia, a not for profit organisation that banks cell lines for drug discovery and disease research[31].
- Scaffold databases contain information about biomaterials that provide a 3D scaffold for attachment of muscle and fat cells. Scaffolds made from biomaterials fit for human consumption are essential for the development of structured meats like steak or fish fillets. However, most existing scaffolds are made from human-derived proteins and used for regenerative medicine purposes. It would be useful for scientists to have a collection of edible scaffolds to refer to in developing cellular agriculture products.
- Scale-up demonstration facilities are required to bridge the gap between research and laboratory testing and large scale manufacturing. Scale-up demonstration plants are usually 1500-5000L fermentation tanks but can be as large as 25,000L. They include upstream and downstream processing equipment that can be customised to mimic the process at scale and are a critical part of the scale-up process that allow optimisation of the standard operating processes and equipment that will be used at scale. Without this step, there is little way to know if the success achieved at lab or bench scale can be replicated in large fermentation tanks which perform in different environments and at different optimal conditions.

Left: *Animal free Casein Protein by Change Foods*

- Finally, at-scale plants (250,000L to 2M+ L) with the capability to culture cells and harvest the desired products from cultivated meat and precision fermentation processes at a food industry scale are crucial. While advanced manufacturing capabilities are improving in Australia, there are currently no fit-for-purpose scale-up production facilities for the cellular agriculture industry. As cellular agriculture companies move from prototype to pilot scale over the next five to ten years, the demand for line time at pilot and demonstration scale production facilities will increase dramatically. While some companies will build their own scale-up facilities, contract manufacturing as an alternative would enable outsourcing of processes and capabilities that can be very expensive, time-consuming, or challenging to develop in-house. Consultation with industry found that in order to raise Series A funding, precision fermentation companies are increasingly required to demonstrate they either have their own in-house manufacturing facilities or a signed contract manufacturing agreement which is symptomatic of the competition for manufacturing capacity globally.

At this pre-competitive research stage, cellular agriculture facilities are unlikely to attract private sector investment, particularly if they are focused on enabling the broader field as opposed to a particular company. Government support at this early stage, like that provided by the governments of leaders in the space such as The United States and Singapore, would place Australia at the forefront of the cellular agriculture sector as it develops. The Singaporean government's support of cellular agriculture through its Agency for Science, Technology & Research (A*STAR) and Economic Development Board has included joint collaborations with global cellular agriculture

Above: *University of the Sunshine Coast PhD researcher Lisa Musgrove*

start-ups to establish pilot facilities (including Avant Meats[32] and Perfect Day[25]). In addition, the Singaporean and New Zealand governments established a Bilateral Research Programme on Future Foods in 2020; this included a three-year research project between A*STAR and the University of Auckland focusing on using cellular agriculture technology to produce cultivated meat[33]. Most recently, the Dutch government announced USD$65, the world's largest-ever investment in cellular agriculture[34].

Chapter 04

4.1 Investing in cellular agriculture now will contribute to Australia's long-term policy goals

Australia's evolution from a provider of primary commodities into a competitive knowledge economy with advanced manufacturing capabilities is an ongoing shift, driven by Australian governments and policy makers (example policies elaborated below).

Cellular agriculture offers Australia an exciting opportunity at the nexus between highly advanced technology and manufacturing, and its development aligns with specific and immediate policies of a range of government agencies, including those that aim to:

Expand reputation for high quality and sustainable food and beverages

The government is modernising Australia's agricultural innovation system to drive improvements in collaboration, commercialisation and uptake to grow productivity and competitiveness. Initiatives such as Ag2030[35] set the right foundations that give industry what it needs to reach the goal of a $100B agriculture industry by 2030. The inclusion of cellular agriculture in this plan would support existing commitments that ensure that agriculture remains a profitable, productive and innovative industry that drives growth and job creation in Australia.

Build manufacturing capabilities

The new Australian Government's $1 billion fund for advanced manufacturing seeks to create a more resilient Australian economy with innovations that offer clear value to growing green markets. In line with targeting Australia's existing strengths, advances in cellular agriculture could powerfully advance these capabilities in food and beverage and medical products advanced manufacturing.

Enable product commercialisation through open access research and innovation

Australia is already known for cutting-edge research — and efforts to drive further commercialisation of research has been the focus of significant public investment. This is evident in the Department of Industry, Science, Energy and Research's investments in the Cooperative Research Centres and Industry Growth Centres.

These priorities are also mirrored in other government aligned agencies, such as CSIRO's Future Protein Mission[36].

4.2 Being an "early mover" accelerates Australia's existing capabilities

Cellular agriculture is a field in which the greatest value in the long-term will likely be derived from being an 'early mover', but not necessarily the 'first mover'. Australia has the opportunity to act now, learning from the success stories of first movers, and observing how the market responds to government support and advocacy.

Australia is in an ideal position to capitalise on being an early mover given our:

- Existing world-leading capability in relevant disciplines
- Close collaborative and geographical relationship with the world's 'first mover', Singapore; and
- Strong export relationships and close geographical proximity to the world's largest market for protein in Asia.

4.3 Where to now?

Although many promising developments have been made over the past couple of years, we are now at the stage where national strategic coordination and targeted public investment are needed to propel cellular agriculture into a major new advanced manufacturing opportunity for Australia. This opportunity would powerfully advance Australia's advanced manufacturing ambitions - and enhance our agriculture and biotechnology industries.

Three urgent imperatives are needed to unlock this opportunity:

1. **Developing a skilled and future fit workforce to enable commercialisation and industry growth**
2. **Deepen Australia's cross-disciplinary, open access cellular agriculture research**
3. **Establish at-scale manufacturing capabilities and infrastructure**

These recommendations were developed to serve an expanding community in Australia engaged with cellular agriculture, outlining the collaboration and action needed from state and federal governments, universities, research agencies, and the private sector.

CAA intends to take a critical first step in realising the potential of these imperatives by convening a series of facilitated workshops to identify common challenges and an action plan to overcome these.

As the primary non-profit organisation dedicated to advancing cellular agriculture research and education in Australia, Cellular Agriculture Australia is well-placed to coordinate the efforts of the sector to implement the three priority recommendations.

Please get in touch at **hello@cellagaustralia.org** to be a part of diversifying Australia's food system.

Glossary of terms

Alternative proteins

Meat, egg, or dairy products that are plant-based, cultivated, or fermentation-derived — not animal-derived.

Biomaterials

A biomaterial is a synthetic or biology-derived substance engineered to interact with biological systems, generally for medical or fundamental research purposes.

Bioreactor

Sometimes known as a cultivator, a bioreactor is an apparatus for growing cells under controlled conditions (such as temperature, oxygen levels and delivery of nutrients).

Biotechnology

The harnessing of cellular and biomolecular processes to develop products or services for healthcare, industry, food production, and other purposes.

Cell line

Cultures of a single cell type that can replicate repeatedly and be frozen and revived as needed. Cell culture is the growing of cells (most commonly animal cells) in an artificial, controlled environment.

Cellular agriculture

The production of animal-derived products from cell-based biotechnologies instead of animals. Cellular agriculture uses two main methods:

- **Cell cultivation:** Involves isolating and cultivating animal stem cells to make products such as meat, fat, seafood, leather and foie gras.
- **Precision fermentation:** Involves programming microbial cells (yeast or bacteria) to produce ingredients such as egg, milk fats and proteins. It also makes insulin and the cheese-making enzyme, rennet.

Cultivated meat

Meat produced directly from animal cells making it biochemically identical to conventional meat (including seafood and organ meats). It is also known as cell-based, cultured or lab-grown meat. This production method eliminates the need to raise and farm animals for food.

Genetic modification (GM)

A technique to change the characteristics of a plant, animal or micro-organism by altering their DNA. This typically involves copying a genetic sequence from one organism and inserting it into the DNA of another to produce a desired trait.

Life cycle assessment (LCA)

A methodology for assessing environmental impacts associated with a product, process or service over its life cycle.

Precision fermentation

Culturing microbial hosts such as bacteria or yeast and making them produce specific animal molecules. These can include egg and dairy proteins, other proteins like collagen and gelatin or non-proteins such as fatty acids. Precision fermentation is also an animal-free approach to making growth factors which are a critical input required to grow the stem cells that produce cultivated meat.

Regenerative medicine

Medical treatment designed to replace tissues damaged by injury or disease. It generally involves transplantation of tissues or techniques to stimulate cell regeneration at the site of injury to encourage the restoration of tissue form and function.

Scaffold

In the context of cellular agriculture this refers to the structural support provided for cells to grow upon and may be crucial for whole cuts of meat like steak and fillets. Scaffold design is a key research area. Scaffolds can be fully constructed (via 3D printing) or derived from existing natural structures such as decellularized plant tissues.

STEM

Science, Technology, Engineering and Mathematics.

Stem cell

Unspecialised cells that can differentiate into a variety of cell types, ranging from muscle cells to brain cells.

Synthetic biology

Combining the disciplines of engineering, computer science, cell biology and molecular biology (DNA, proteins, and enzymes) to create novel biological systems for the production of useful substances, devices, and processes.

Tissue engineering

A medical field that applies the principles of cell biology, engineering, biochemistry and materials design to develop, restore, replace or improve biological tissues. This typically involves stem cells being grown upon scaffolds to recreate three-dimensional tissues.

Above: *Food preparation and tasting at Nourish Ingredients*

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Inside back cover: *Cultivated Bacon with Pancakes by Higher Steaks*

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