July 2023

Unleashing Aotearoa New Zealand's next protein revolution.

Emerging Proteins NZ

food HQ
Where food ideas meet science

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Report Context + Approach

Protein diversification is a value-add

The global demand for high quality protein from a diverse range of sources is growing as awareness is rising regarding the role protein plays in a healthy balanced diet. In recent years, the growth in the consumption of protein has outstripped the increase in the global population as many societies have become wealthier.

Predicting future protein demand is beyond the scope of this report, but research suggests that at a minimum protein demand will remain at least the same as at current levels but, with increasing urbanisation, wealth and an interest in well-being demand will most likely be higher than it is today. Keeping up with protein demand is also crucial for economic reasons. However, protein production will become more difficult with increasing extreme weather events impacting growing conditions, sustainability demands of consumers concerned with greenhouse gas emissions and the anticipated population growth.

To overcome these difficulties, **innovation in the protein supply market is rapidly expanding**. Many farmers, entrepreneurs, inventors, scientists, and foodies are 'racing' to find the next scalable, sustainable source of protein.

Whilst Aotearoa New Zealand has been at the forefront of producing high-quality protein from grass-fed meat and milk for many decades, it has taken a backseat in the emerging proteins race for many years. In September 2022, FoodHQ published a report[1] that showed New Zealand does not have an emerging protein strategy and that its investment in this sector has been limited to date. The FoodHQ report did not go as far as to make recommendations on actions the New Zealand government could take, however similar themes from that report were recently highlighted by Te Puna Whakaaronui who wrote that[2]:

> *"We are already 3-5 years behind in some product classes [in the emerging protein sector] and do not have the resources to compete in many of these categories. Understanding where New Zealand can compete and create long-term value is critical."*

The opportunity for new, emerging sources of protein* **as a complimentary source of added-value** for primary producers has never been better. The possibility for New Zealand to **add value to its land and traditional protein industries** is attractive, exciting even, especially for existing sectors to apply their capability and infrastructure to build resilient, diversified landscapes and commercialise new products in new markets. Consequently, if we do not diversify our proteins sector, **New Zealand risks losing the opportunity to develop new export markets** to meet growing consumer demand seeking new food choices.

As a small country we have constraints on the resources we can invest into the development of our emerging proteins sector, so we need to make informed choices. We are at the point where New Zealand needs to evaluate the role it plays in the emerging protein market, consider how best to enter the 'race,' and understand where investment is best placed to take advantage of our uniqueness.

The intention of this report is to help New Zealand accelerate its decision-making regarding how (or if) it chooses to take part in this rapidly moving novel agrifood sector.

* Throughout this report the term 'emerging proteins' is used rather than 'alternative proteins'. This reflects our position that these protein sources are complementary to existing traditional sources of protein, and that it is not necessary to position one as being 'alternative' to the other.

How to Read the Report

The report that follows has been based on an in-depth analysis of the emerging protein market using publicly available information. **The report contains information on ten major emerging protein sources that are laboratory-based, plant-based or other sources**. There are three additional emerging proteins included under the title – ones to watch.

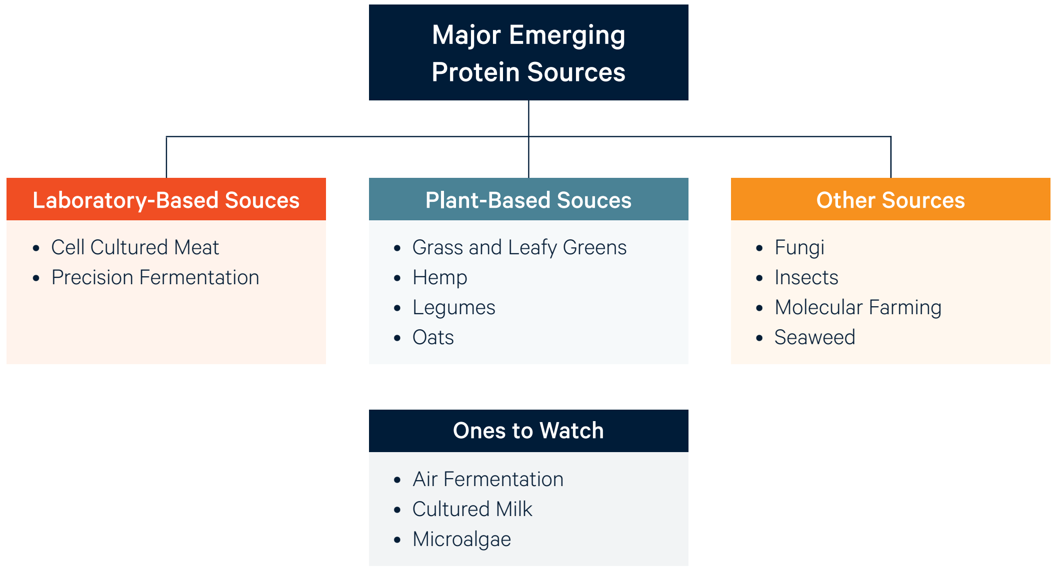


Figure 1. Emerging Protein Source Categories

For each of the ten emerging protein sources, there is information on **what** each source is. This is followed by a **SWOT** (strength, weakness, opportunity, and threat) analysis that considers each source within New Zealand's unique context. Finally, some thoughts are provided for each source on the **so what** to drive forward our conversations on the future of this sector (if you are after a quick read – then head straight for this section of each emerging protein).

The 'ones to watch' are still in the concept stage so there is only a brief synopsis on each of these included.

Following these sections, the report concludes with some **Food for Thought**. This is where we propose the four emerging protein sources that we feel New Zealand may be best placed to explore given our unique competitive advantages.

As you read the report you will see a 'rating' has been given to each of the emerging proteins using a matrix to assess how each of them rated against four areas: (international) competition, regulation, natural resources and know-how. Each emerging protein was given a 'score' for each of these areas using the matrix. The scores were totalled and a star rating applied: five star being the highest rating and one star being the lowest rating. The matrix and score table are included in Appendix 3.

02

Laboratory-Based Sources

Cell Cultured Meat

What?

Cell cultured meat, also referred to as cultivated meat, is produced by cultivating animal cells to replicate traditional meat at a cellular level. Animal cells are grown in a nutrient-rich cell culture medium containing sugar as a main feedstock along with a mixture of amino acids, vitamins, salts and growth factors. This is placed inside a bioreactor under controlled conditions to form muscle tissue that can be harvested and processed into meat products[3]. **Such products aim to mimic the taste, texture, and nutritional composition of animal meat (or seafood) by using identical cells**. It has been estimated that the production of cultured meat will have minimal land and water requirements, as well as its lower GHG emissions[4], thus some have said **it could be a more sustainable approach to producing meat**.

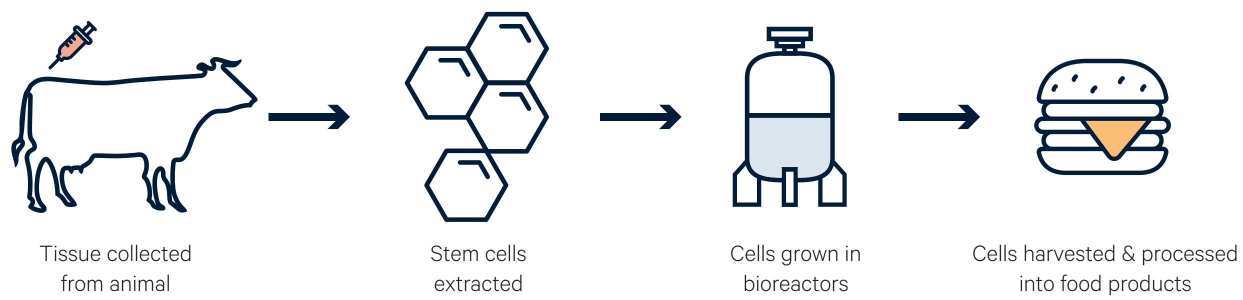


Figure 2. Cell cultured meat process infographic

Global Context and Development

In their 2022 State of the Industry report[5] on cultivated meat, the Good Food Institute (GFI) indicated that there were more than 150 companies active across the cultivated meat or seafood landscape. **Capital investment has totalled an estimated NZ$4.4B, with almost a third of the investment occurring in 2022**. Most companies are still in the R&D or pilot stages; however, cultured meat has been approved for sale in Singapore[6] and just recently in the United States[7]. Counter to these moves, in Italy a government bill to ban cell cultured meat and other synthetic foods was recently supported by the Italian government, on the grounds of protecting Italian food heritage[8].

Major companies producing cell cultured meat include Upside Foods, Mosa Meat, Believer, and Aleph Farms. Whilst several large food companies such as Tyson Foods, Cargill and Nestle have invested in the industry[9, 10], indicating that it is becoming increasingly mainstream. **Australian company, Vow, opened the largest cultivated meat facility in the southern hemisphere in Sydney, with capacity to produce up to 30 tonnes of cultivated meat annually**[11]. Whilst this is considered a large amount of cultivated meat, for context, in 2018-19 the Australian beef industry produced 2.4 Mt of beef and veal[12]. Vow have recently applied to FSANZ for food safety approval.

In 2022, **the Dutch government invested NZ$103M of public funding** to support the formation of an ecosystem around cellular agriculture – or cultivating meat directly from cells – and producing animal-free dairy. It represents a first step towards funding a larger growth plan proposing to invest NZ$433-658M in cellular agriculture stimulating education, academic research, publicly accessible scale-up facilities, societal integration (including farmers and consumers) and innovation.

Current State in Aotearoa New Zealand

The NZ$3 million Catalyst Future Foods project has been established to enable New Zealand scientists to collaborate with colleagues in Singapore to develop hybrid foods: that combine plant-based proteins with cultured meat. **New Zealand scientists are researching alternatives for growth factors which have historically come from foetal bovine serum**. Growth factors are essential for the growth of animal cells, the aim is to find ethical and sustainable alternatives, such as plant-based or synthetic sources[13].

Opo Bio Aotearoa are focused on producing cell lines that can be used by producers of cultured meat. This means they do not need large capital investment in bioreactors, as they are producing the cell lines, not the cultured meat. Their point of difference is the use of high-quality livestock from Aotearoa New Zealand[14]. Launched in July 2022, they recently raised a NZ$1.5 million of seed funding and have bovine cells, that they state can grow without serum within suspension bioreactors – available for purchase. Their long-term objective is to establish themselves as the leading developer and supplier of cell lines[15].

SWOT Analysis

S

Strengths

- **Product quality:** Cell-cultured meat is intended to replicate the taste and texture of meat.
- **Environmental impact:** It is estimated that cell-cultured meat place low demands on land and water, whilst producing lower GHG emissions if renewable energy sources are used.

W

Weaknesses

- **Capital investment:** It is estimated to cost NZ$95M for a large-scale production facility that could produce 540 tonnes of product annually[16].
- **Profitability:** Production costs remain high, even with assumptions around technology improvements production is estimated to cost NZ$100/kg[16].
- **Supply chain:** New Zealand has no commercial scale sugar cane production, creating a dependence on international suppliers for feedstock.
- **Scale up challenges:** Whilst research has demonstrated feasibility of extraction at a lab scale, large-scale commercial extraction is yet to be achieved.

O

Opportunities

- **Ground mince:** Usually produced from off-cuts from an animal, these off-cuts may no longer have a purpose after the introduction of cultivated meat.
- **Reputation:** New Zealand's meat products have a strong global reputation that could be leveraged through the sale of cell lines from its high-quality livestock. This B2B focus would minimise capital investment in large-capacity bioreactors.
- **Market growth:** Cultivated meat may well be an alternative protein that is closest to meat in terms of texture and flavour and may therefore be an attractive alternative protein.
- **Know how:** We have significant expertise in science and microbiology that could be upskilled in knowledge specific to the production of cell-cultured meat.

T

Threats

- **Energy demand:** It is imperative that bioreactors utilise renewable energy sources to minimise GHG production and uphold sustainability claims.
- **Nutritional quality:** It is unknown whether the essential fatty acid, vitamin, and mineral content, will replicate that of traditional animal products[17].
- **Regulatory challenges:** Cultured meat is not yet approved for sale in New Zealand.
- **Public perception:** Whilst consumers express willingness to try cultured meat[18], it it's uncertain whether this will translate to actual consumption, or whether plant-based consumers – such as vegans – will be willing to consume such products.

2 Stars

So What?

- The cell-cultured meat industry is attracting significant global investment because **it has the potential to be a sustainable method of producing meat**. With the global meat market valued at NZ$2,087B19, cell-cultured meat has an opportunity to participate in and potentially capture a relevant portion of this.
- It is still early days in New Zealand for this technology and **more research and development work is needed** for regulatory approval and consumer acceptance.
- The capital investment and production costs associated with cell cultured meat production may be a barrier to entry for New Zealand companies. **There could be opportunities for licensing intellectual property** or focusing on B2B sales of cell lines rather than large-scale production.
- For the New Zealand industry, **challenges would exist with supply chain control** since one of the major feedstocks, sugar, is not produced domestically. This creates a dependence on international suppliers and presents risks related to availability, cost, and quality.

Precision Fermentation

What?

Precision fermentation uses microorganisms as hosts to produce specific target proteins, or other compounds, in a controlled environment with a refined sugar-based feedstock. This process has been used for decades to produce hormones such as insulin and enzymes involved in food processing[23]. **It can be used to produce traditional animal proteins, whey protein for example, without the use of livestock**.

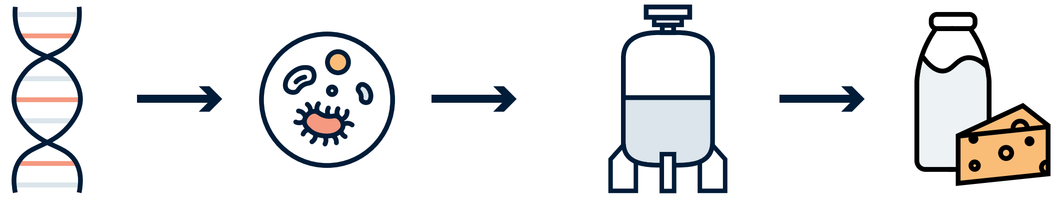


Figure 3. Precision fermentation process chart

Proteins produced via precision fermentation are not replicating the diverse range of proteins found in whole animal products, rather, **they are creating specific individual proteins that are found within animal products**. However, precision fermentation has been reported to have a smaller environmental impact than livestock agriculture, making it **a more sustainable source of animal protein**[23]. When precision fermentation is used to create a specific protein, such as one of those found in milk, it does not replicate the complete nutritional profile of the whole food. Thus, products will require the addition of other ingredients, or fortification with vitamins and minerals, to be comparable nutritionally to conventional animal products.

Global Context and Development

In their 2022 State of the Industry report[20] on fermentation, the Good Food Institute indicated that there were 62 companies active in the precision fermentation landscape. **Annual investment into precision fermentation has totalled nearly NZ$3.2B since the first investments in 2013**. More than 50% of the total investment has occurred in the last two years.

Whilst many companies are still predominantly at the research and development stage or pilot stage, **there are products on the market that contain ingredients produced by precision fermentation**. The major player in the commercial space currently is Perfect Day[20], their ingredients are found in products such as Brave Robot's range of ice cream sold in the US, Strive's range of milks sold in the US and Canada, and California Performance Co.'s V-whey range of whey proteins sold in the US, Hong Kong, and Singapore. Outside of the dairy protein category, Geltor[24] is a company who produce a variety of proteins, including collagen, that are utilised by cosmetic companies as well as having commercial application in the food and nutrition sectors.

Current State in Aotearoa New Zealand

Fonterra have established a new start-up company with Dutch multinational corporation Royal DSM aiming to accelerate the development and commercialisation of precision fermentation proteins with "dairy-like properties"[25]. This **will accelerate commercial product solutions from previously filed patents**, while continuing new research and development.

Daisy Lab is a New Zealand start-up, based in Auckland, working on producing dairy proteins by precision fermentation. Their research was initially into casein protein, and they are now looking at whey protein. They recently closed a NZ$1.5M seed round which they will use to scale up their production of whey proteins whilst continuing research on caseins[26].

SWOT Analysis

S

Strengths

- **Know-how:** We have existing expertise and knowledge in fermentation from other industries, such as dairy.
- **Environmental impact:** Protein produced through precision fermentation is claimed to produce up to 97% less GHG, use 99% less blue water and up to 60% less non-renewable energy compared to protein found in traditional milk[27].
- **Nutritional quality:** Any specific protein can potentially be produced by this method, such as high-quality dairy proteins such as casein and whey.

W

Weaknesses

- **Capital investment:** Commercial facilities that could produce 10,000+ Mt annually are estimated to cost NZ$238-636M for new facilities or NZ$159-413M utilising repurposed fermenters[28], [29].
- **Supply chain:** Large quantities of sugar cane is used as feedstock in precision fermentation creating a dependence on international suppliers.
- **Waste:** Some limitations exist with circularity, especially given the potential to contain genetically modified organisms

O

Opportunities

- **Novel applications:** Given precision fermentation can theoretically produce any protein, there is the potential to create novel proteins and thus create valuable products.
- **Feedstock:** By-products from other industries could be used as feedstocks, however, considerable research and development is needed to ensure efficiency is maintained.
- **Energy demand:** Large energy inputs are required for optimal fermentation conditions, New Zealand's abundant renewable energy supply could enable for low-impact production

T

Threats

- **Regulatory challenges:** New Zealand's stringent regulatory environment related to genetic engineering and genetic technologies do not permit the domestic production of food from precision fermentation[22].
- **Competition:** There are already well-funded competitors internationally that have achieved scale of production who will present a challenge to capturing market share.

2 Stars

So What?

- New Zealand's current genetic engineering and **genetic technology regulations preclude the use of precision fermentation to produce food products domestically**. Therefore, if New Zealand wants to become a player in this space, a wider conversation around the use and regulation of genetic technologies needs to take place.
- Within the current regulations, New Zealand companies would need to consider alternative business models, such as international partnerships, licensing, or intellectual property development.
- If regulations were altered to allow domestic production, challenges would exist with supply chain control since the major feedstock, sugar, is not grown here. High dependence on international suppliers presents risks related to availability, cost, and quality.
- Any **large capex investment would need a feasibility study completed** to understand the economic viability of establishing a production facility within New Zealand.
- **Precision fermentation has been predicted to disrupt the dairy industry in the future**[30], and New Zealand, as a dairy-producing nation, should keep a close eye on this technology.

03

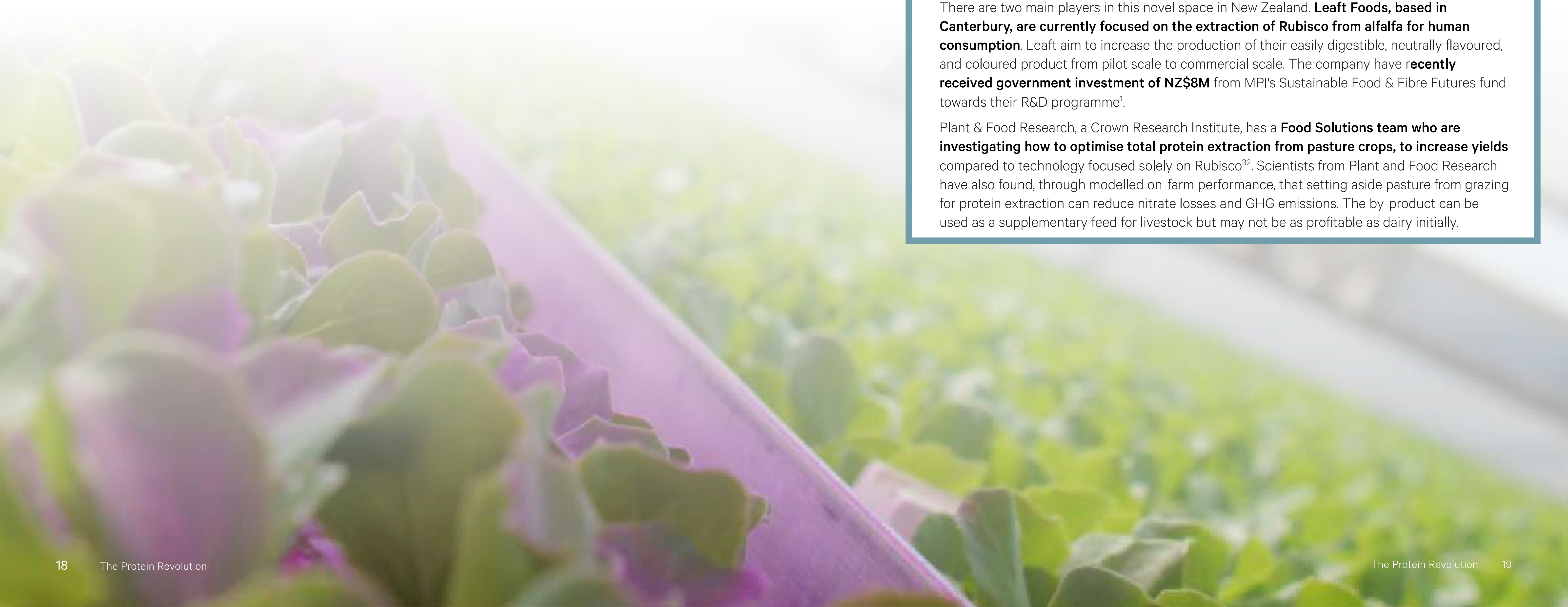
Plant-Based Sources

Grass and Leafy Greens

What?

Grasses are a crop commonly utilised for grazing animals, whilst leafy greens refer to a diverse range of vegetables known for their edible leaves – such as spinach and lettuce. **They are sources of complete protein, but it is not feasible for humans to consume the volume of produce required to obtain adequate protein from the whole food**. One of the main proteins contained within grass and leafy greens is Rubisco. It was first extracted over 100 years ago, but efficient extraction of Rubisco at scale has not yet been achieved. Proprietary systems and methods have been developed but remain in the R&D or pilot stages.

Rubisco concentrates have diverse applications, as a functional food ingredient or as a plant-based protein powder. Rubisco proteins are classified as a complete protein and as an ingredient they have excellent foaming properties, and serve as emulsifiers or gel-forming agents[31]. A cellulose by-product is being investigated for use as a substrate for low-emissions vehicles[32]. While waste from the extraction process can be used as a supplementary feed “cake” for cows, which due to its lower nitrogen content may help to minimise nitrate losses from livestock.



Global Context and Development

Protein concentrates from grass and leafy greens would form part of the global plant protein market, which could reach NZ$57B by 2024[33]. Within the last five years more than NZ$95M has been invested into companies for the commercial extraction of Rubisco and other proteins from grass and leafy greens[31].

Some examples include Plantible Foods in the US who raised NZ$42M to extract protein from duckweed; the Plant Protein Factory in Sweden which extracts plant protein from green biomass; and Rubisco Foods in the Netherlands[31] who sell plant protein concentrates from alfalfa and water lentils. Rubisco from water lentils was just given official confirmation as being food safe by the European Food Standards Authority[34]. Wageningen University & Research have also demonstrated it is possible to extract protein from tomato leaves[35].

Current State in Aotearoa New Zealand

There are two main players in this novel space in New Zealand. **Leaft Foods, based in Canterbury, are currently focused on the extraction of Rubisco from alfalfa for human consumption**. Leaft aim to increase the production of their easily digestible, neutrally flavoured, and coloured product from pilot scale to commercial scale. The company have r**ecently received government investment of NZ$8M** from MPI's Sustainable Food & Fibre Futures fund towards their R&D programme[1].

Plant & Food Research, a Crown Research Institute, has a **Food Solutions team who are investigating how to optimise total protein extraction from pasture crops, to increase yields** compared to technology focused solely on Rubisco[32]. Scientists from Plant and Food Research have also found, through modelled on-farm performance, that setting aside pasture from grazing for protein extraction can reduce nitrate losses and GHG emissions. The by-product can be used as a supplementary feed for livestock but may not be as profitable as dairy initially.

SWOT Analysis

S — Strengths

- **Protein quality:** The protein extracted is a complete protein, with neutral flavours and a range of favourable properties as a food ingredient.
- **Natural resources:** New Zealand has a favourable climate, with abundant rainfall in many regions, alongside ample land area suitable for the growth of forage crops.
- **Know how:** New Zealand is an experienced and efficient producer of forage crops.
- **Diversification opportunity:** Farmers could allocate a section of land for protein extraction, diversifying income streams and reducing greenhouse gas emissions[32].
- **Product innovation:** New Zealand's food industry is recognised for its innovative approaches in agriculture, farming, and food processing.

W — Weaknesses

- **Scale up challenges:** Whilst research and industry have demonstrated feasibility of extraction at a lab and pilot scale, large-scale commercial extraction hasn't been achieved.
- **Capital investment:** High levels of up-front investment for processing facilities – estimated at NZ$100M[36].
- **Profitability:** Has previously been shown to have only marginal economic viability. This could be improved through enhanced protein extraction processes alongside improved protein content in crops[36].
- **Location constraints:** Crops must be grown near processing facilities to avoid degradation of the produce from harvest to processing.
- **Required volumes:** Approximately one tonne of leafy material is required to get 6kg of Rubisco[31] (i.e., 0.6%). Given its low density, this increases bulk and could present logistical challenges.

T — Threats

- **Alternative land uses:** The potential for higher profits from traditional land uses, such as dairy, may inhibit adoption.
- **Economies of scale:** Overseas plant-based protein products grown and produced at scale can achieve low price points.
- **Demand:** Our domestic demand for plant protein concentrates is currently limited, thus export markets should be considered.

O — Opportunities

- **Market growth:** New Zealand is well placed as an early adopter of the technology, within a rapidly expanding global plant protein market.
- **IP potential:** Weightless exports of domestically created IP.
- **Environmental impact:** If by-products are used as livestock feed, nitrogen losses from livestock can be reduced.
- **Expertise:** The dairy industry's engineering expertise and manufacturing capability could potentially be leveraged for plant protein manufacturing.

4 Stars

So What?

- Rubisco protein **has excellent properties as a neutral tasting ingredient with good foaming, emulsifying and gelling qualities, as well as being a source of complete protein**. It has many potential applications, providing opportunities to develop valuable food products rather than simply be a bulk additive.
- This is at an early stage of research and development, so proof of concept at a commercial scale is needed. **Any large capital investment would need a feasibility study completed** to understand the economic viability of establishing an extraction facility in New Zealand.
- **There is a growing market** for this type of protein and New Zealand could pioneer the technology which has potential as a weightless export.
- Waste through the extraction process could be minimal with possible applications as animal feed and bio-fuel by-products.
- **Growing the volumes required would need to be incentivised**, but there are climate change benefits if used in a crop rotation system.

Hemp

What?

Hemp seeds are produced by the industrial hemp crop and are made up of a third each of oil, protein, and fibre. They are a nutrient dense food source, containing a range of vitamins and minerals, as well as essential fatty acids – such as Omega 3 and 6[37]. **The protein can be extracted from the seed and utilised in a supplemental form or as an ingredient in a range of food products from snack bars to cereals**. Alternatively, the seeds themselves can be eaten or ground into a fine powder and utilised as a flour.

Figure 4. Hemp seed products available in New Zealand

Protein extraction methods vary based on the desired product and could include screw pressing or hexane treatment to remove oils (which can be used as a plant oil), followed by using alkaline/acid extractions, micellization or enzymatic digestion[38]. **The final hemp protein concentrate is a complete and digestible protein, making it is a high-quality plant protein**.

Typically, industrial hemp is grown for one purpose, but there is the **potential to grow crops with dual applications**[39]. The dual-purpose varieties have disadvantages with lower seed production, or poorer quality fibre. But a seed-focused crop can still produce crops with fibre applications to industries such as paper. This is a potential **value add for farmers** who are growing crops for seed to increase their revenue and achieve total utilisation.

Global Context and Development

A report from Mordor Intelligence40 stated that **the global hemp protein market was valued at NZ$95M and was projected to grow to NZ$117M in 2026**. The compound annual growth rate (CAGR) was estimated to be 3.95% from 2021-2026. The market leaders were said to be Tilray of Canada. However, the wider plant protein market could reach NZ$57B by 2024[33] and hemp has potential to claim a larger than anticipated stake within that if its **potential as an ingredient in plant-based meat analogues is realised**.

A 2022 United Nations Commodities at-a-Glance report provided insights on industrial hemp[37]. Stating China has always led the production of industrial hemp, but their focus has been on its fibre applications, with France also being a historical producer. More recently, Canada and the United States have become significant producers with a greater influence on global markets. The estimated global value of the industrial hemp market was NZ$8B – demonstrating that hemp protein is currently a small part of the total hemp industry.

Current State in Aotearoa New Zealand

Our hemp industry is still in its infancy. Growing industrial hemp domestically has only been possible since the Misuse of Drugs (Industrial Hemp) Regulations 2006, and it has been less than five years since hemp seed has been allowed to be sold as food, after the Food Regulations 2015 were amended in November 2018[41]. While a market size was unable to be determined, **a variety of commercial hemp food products are available domestically**. Examples include hemp seeds and hearts, hemp oil, hemp protein powder and hemp flour. Sustainable Foods Limited launched a hemp chick*n product in 2022. The only New Zealand grown hemp product currently being produced as meat alternative.

SWOT Analysis

S

Strengths

- **Natural resources:** We have several regions considered suitable for growing hemp, such as Canterbury and the Hawke's Bay.
- **Environmental impact:** Hemp is a fast-growing crop that requires less water and pesticides than many other crops. It also has deep roots that help to improve soil health and prevent erosion.
- **Know how:** New Zealand has a history of expertise related to plant science and food production.
- **International recognition:** Our reputation as a producer of clean and green food resonates with reasons why consumers may choose hemp products.
- **Nutritional quality:** Hemp seeds are a complete source of protein as well a variety of vitamins, minerals, and essential fatty acids.

W

Weaknesses

- **Capital investment:** The unique characteristics of the hemp crop require specialised equipment to be efficiently harvested and processed.
- **Location constraints:** Hemp seeds need to be quickly dried following harvest to avoid degradation. Growers must ensure their proximity to the limited number of suitable processing facilities[42].
- **Competition:** There are well-established hemp protein competitors internationally that will influence the ability to obtain market share within our traditional export markets.

O

Opportunities

- **Total utilisation:** It is possible for growers to minimise waste and maximise profitability through utilising the entire plant.
- **Market growth:** If hemp protein realises its potential as a food ingredient it could compete for a greater share of the plant protein market, predicted to be worth NZ$57B by 2024[33].
- **Increasing yield:** Further trials of specific cultivars in suitable regions could help to increase yield and profitability. Only 20 cultivars are approved by the Ministry of Health for growers[2].
- **Improving extraction:** The development of innovative extraction technologies could enable the production of high-quality hemp protein extracts with higher yields and lower processing costs.
- **Price:** Is a major driver of product choice, so there may be an increase in uptake once these products are as cheap, or cheaper than meat products.

T

Threats

- **Regulatory challenges:** Understanding and overcoming regulatory hurdles is currently a barrier to entry, or a friction point.
- **Profitability:** Currently hemp is grown either for seed or fibre, and thus growers will choose which application based upon revenue generated. Given growing for protein is a more novel application, profitability is still unclear.
- **Public perception:** Poor public perception of hemp due to its association with marijuana may have an impact on demand.

4 Stars

So What?

- **Hemp seeds are a nutrient-rich source of protein** with essential fatty acids and various vitamins and minerals. Hemp seed protein has applications as an ingredient, such as use in plant-based meat alternatives.
- **Total utilisation of the hemp crop could minimise waste** and generate additional revenue streams. Dual purpose hemp crops have been grown in New Zealand[43], but they do require greater upfront investment for specialised equipment.
- Increased access to processing facilities and specialised equipment for harvesting and processing would help to expand the possible growing regions of industrial hemp for seed.
- **Targeted research programmes** into hemp cultivation, processing, and product development specific to our local conditions could help unlock the full potential of the crop and **support the growth of a thriving hemp protein industry**.
- Facilities are now available in New Zealand to create extruded products at scale.
- Educating consumers about the nutritional and environmental advantages of hemp could boost demand by **addressing negative perceptions** due to its association with marijuana.
- Whilst the market is growing, **there is established competition from international suppliers**, which could have a significant impact on potential returns and export channels.

Legumes

What?

Despite being a rich source of protein, legumes are not consumed in high amounts globally, with the average person consuming more than five times as much meat per day compared to legumes (see figure 8 below). **Legumes are a sustainable protein source because of their low greenhouse gas emissions and water consumption, as well as their nitrogen fixation abilities**[44].

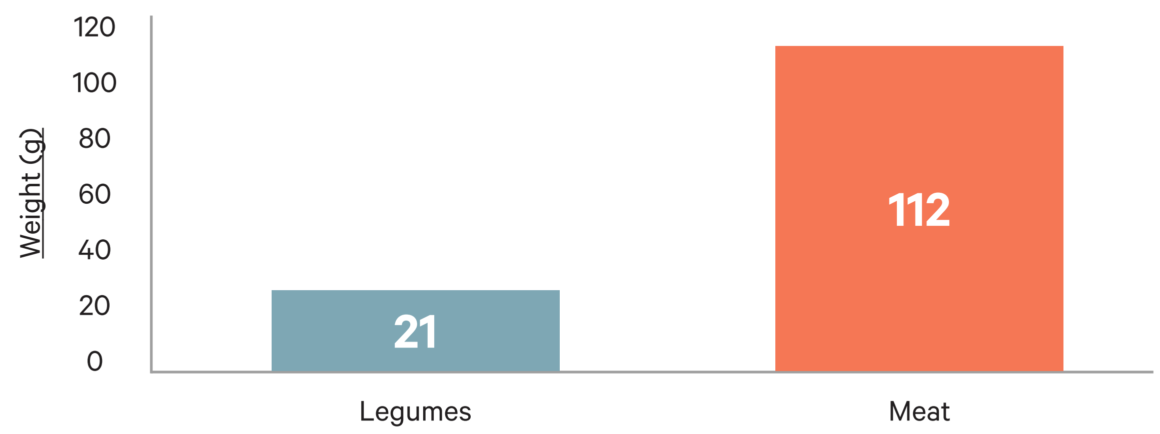


Figure 5. Global daily consumption of legumes vs meat

Legumes also play a key role in the production of many plant-based meat alternatives. Soy is the most widely used because it has a neutral taste, pea and fava bean are growing in popularity due to their emulsifying capabilities and the essential amino acids they contain. Through using legumes in plant-based meat analogues, **manufacturers have been able to create nutritious, high protein, sustainable products**. However, these plant-based meat analogues still tend to be more expensive than the products they imitate.

Figure 6. Legume-based meat analogue products available in New Zealand

Global Context and Development

The most widely produced legume is the soybean. However, in 2019, of the soybean meal produced by the US, less than 1% went to producing food for people, the majority to feeding poultry and pigs. Many legumes show similar patterns, so if legumes were to be a more commonly consumed source of protein for humans, **there would need to be redirection of legume production towards providing food for humans as opposed to livestock**[44].

The **plant-based protein market is a growth market**, with the major legume-based protein markets being for soy and pea. Soy protein is dominant in the plant-based protein market and was estimated to be valued at NZ$12.2B in 2022 and is predicted to grow to NZ$17.2B by 2027[45]. Whilst the pea protein market was estimated to be valued at NZ$2.7B in 2022 and is predicted to grow to NZ$4.6B by 2027[46]. Impossible Foods uses ingredients derived from legumes in many of their products, such as soy protein concentrate in both their Impossible Beef and Pork products. Another legume growing in popularity is the **fava, or broad, bean which has recently been incorporated into Beyond Meat products**.

Current State in Aotearoa New Zealand

Our domestic production of legumes was classified as 'not adequate' in a 2021 publication by Curran-Cournane and Rush[47]. They found that to have one serving of domestically produced legumes per day we would need to increase our production by 76%. Thus, our current production is relatively low, and based on a recent report we only plant peas and beans at a commercial scale – predominantly in Canterbury and the Hawkes Bay[48].

Whilst we grow peas, we do not currently produce our own pea protein concentrate and thus must import enough to meet our demands (530t). Currently the market in Aotearoa New Zealand demands pea protein predominantly for sports nutrition (85%) and alternative meat (14%) products. Companies will utilise imported pea, and other legumes, for protein to produce plant-based products – some of which are then exported. For example, Sunfed and plan*t utilise pea protein in their products. **Modelling indicates potential growth in the market of 10x in the coming decade**, however, this is dependent on a variety of assumptions[49].

SWOT Analysis

S

Strengths

- **Know how:** New Zealand has experienced growers of specific types of legumes, such as peas and beans[9], and we are familiar with producing protein concentrates and isolates, but predominantly from dairy.
- **Protein quality:** The protein extracted from peas and soybeans is a complete protein and has been used as an ingredient in meat analogues and other plant-based products.
- **Environmental impact:** Protein from legumes is considered low emissions and growing legumes can help to fix nitrogen in the soil, improving soil health and reducing the need for synthetic fertilisers.

W

Weaknesses

- **Economies of scale:** Competitive pricing is achieved by growing legumes and extracting proteins at a large scale overseas.
- **Capital investment:** To produce high value products, such as pea protein concentrates, new facilities are required – estimated at NZ$50M to produce 15,000 tonnes per year[50].
- **Consistency of yields:** Legumes are known to have significant fluctuations in yield and are prone to losses from pests and environment.

O

Opportunities

- **Market growth:** The domestic market for pea protein is expected to grow 10x in the next ten years and other countries, such as the US, have had estimated annual growth rates of around 10%[49].
- **Crop rotation:** Legumes could be grown as part of a crop rotation system, helping to break disease cycles and improve soil structure.
- **Fava bean:** Is a legume not currently well-utilised but has many beneficial properties as a protein concentrate and could present a suitable legume crop for New Zealand conditions.

T

Threats

- **Competition:** International markets have established suppliers which could make it more difficult to access our traditional export markets.
- **Product price points:** Plant-based meat analogues made from processed legumes are more expensive than the products they imitate.
- **Public perception:** Traditionally legumes have been known as "the poor man's meat", as wealthier people could afford to consume meat[44], which could impact demand.

4 Stars

So What?

- Legumes offer a **sustainable and nutritious protein source** that could play a role in meeting the protein needs of a growing global population.
- To fully realise the potential of whole legumes as a protein source, it is **important to address barriers related to cooking methods** and the traditional perception of legumes as a food for those of a lower socioeconomic status.
- Domestic production of legume-based protein concentrates in New Zealand could offer advantages in terms of quality control, reduced transportation costs and carbon footprint, but **economies of scale may present a challenge in achieving cost parity with imported products**.
- New Zealand would **require significant capital investment to produce protein concentrates from legumes**. However, collaboration among industry players or government investment could be possible options to address this challenge and enable the domestic production of these products.
- The growing demand for plant-based proteins presents a **significant opportunity for legumes as an emerging protein source in New Zealand**, but competition from well-established international suppliers may impact export channels and profitability.

Plant-Based Sources

Oats

What?

As a whole food, oats have one of the highest levels of protein for a commercially grown cereal and are a rich source of fibre and a range of micronutrients[51]. **Whilst oats are a source of plant protein as a whole food, they are commonly consumed as a plant-based milk alternative**: a substitute for dairy milk for those with allergies or following vegan diets and is currently the primary oat-derived product in the emerging proteins space.

Figure 7. New Zealand Oat Milk Companies

To make plant-based milk, oats are blended with water and strained to remove solids. The result is a creamy, smooth milk alternative, which because of its flavour and texture has become popular. However, **it contains less than a third of the protein of standard blue milk and its protein is considered incomplete**. It also requires fortification with vitamins, minerals and bio-available nutrient to meet dairy milks nutritional value related to micronutrients such as calcium and vitamin B12.

Plant-Based Sources

Global Context and Development

Sweden and Finland have traditionally been some of the largest producers of oat milk globally. However, the industry is expanding with many other producers entering the market from across the globe due to **increased demand from consumers seeking non-dairy milk alternatives**. Environmentally, it production has a much lower freshwater use than almond milk and similar GHG emissions to both almond and soy milks[52].

Globally **the oat milk industry is worth more than NZ$3.4B and rising**, but it is still far behind its almond (NZ$7.6B) and soy (NZ$9.1B) milk counterparts[53]. In the US, oat milk is second only to almond milk for sales in the plant-based milk category, it has risen from 0.5% of this category in 2018 to 17% in 2021[54]. Whilst in the UK, oat milk is the most popular plant-based milk choice, with NZ$288M spent as opposed to NZ$207M on almond milk[55]. In Australia, oat milk has yet to surpass almond or soy in popularity, but it is predicted to do so in the next 18 months[53].

Current State in Aotearoa New Zealand

Domestic sales of plant-based milk alternatives nearly tripled from 2017 to 2019, growing from NZ$52M in 2017 to NZ$144M[56]. Of the major plant-based milks, we only grow one base ingredient – oats – at commercial scale. We have several domestic companies selling oat milk, but at present **only Boring are processing locally grown oats in New Zealand**. Others using locally grown oats to produce oat milk but export the oats overseas, typically to Europe, to be processed into milk which is then returned to New Zealand to be sold. However, this will change with new processing plants that are planned to be built[56, 57].

SWOT Analysis

S

Strengths

- **Production practices:** New Zealand has a history of growing oats, particularly in the Southland region[51].
- **Know-how:** We have significant knowledge and experience in food processing that can be applied to the production of oat milk.
- **Natural resources:** There is an additional 200,000 ha of land in Southland alone classified as 'high' or 'moderate' versatility to arable farming[51].
- **Environmental benefits:** Oats have one of the lowest impacts on the environment, across various domains, compared to both dairy and other plant-based milks[52].

W

Weaknesses

- **Profitability:** Oats don't have a high profit margin compared to other land uses[58]. Exporting liquid milk to international markets from New Zealand could prove expensive.
- **Waste:** A considerable proportion of the oat plant used to produce oat milk remains as a pulp by-product that must be utilised to minimise waste.
- **Nutritional value:** Whilst oats contain all nine essential amino acids, they do not contain enough of each to be considered a complete protein, and oat milk requires fortification to achieve a similar micronutrient profile to dairy.

O

Opportunities

- **Market growth:** If oat milk continues to take market share from other plant-based milks, as it has been doing, it has the potential to significantly increase on its NZ$3.4B global sales.
- **Planned processing plants:** A factory is planned in Southland with backing from government investment, that could produce up to 80 million litres of oat milk per year[56]. As well as a facility in Auckland with capacity of up to 50 million litres per year[57].
- **Total utilisation:** Potential to utilise by-products of oat processing as animal feed or potential for other higher value products.Total utilisation: Potential to utilise by-products of oat processing as animal feed or potential for other higher value products.

T

Threats

- **Alternative land uses:** Repurposing land to grow oats presents challenges as other uses are considered more profitable for farmers – and may be well established, such as dairy[58].
- **Competition:** Well-established competitors internationally could influence market share within potential export markets.

4 Stars

So What?

- **Oat milk presents a fast growth market** within the expanding plant-based milk alternatives category. There is an opportunity to capture market share nationally and internationally.
- To fully capitalise on production capacity of the proposed processing facilities, **a focus on export markets is essential**. Appropriate market research and a well-thought-out strategy will be crucial to differentiate domestic products and enter specific export markets.
- To encourage farmers to grow oats, it is **essential to demonstrate the positive environmental impact of oat farming** or provide other incentives, as profitability alone may not be sufficient to attract farmers away from more lucrative land uses.
- As domestic processing capacity scales up, it is important to consider the potential uses of by-products, particularly the oat pulp, to enhance profitability and minimise waste.
- Although oat milk serves a specific market as a plant-based milk, **its protein content per serving is relatively low**, which means it may not be regarded as a significant source of protein for consumers.

04

Other Sources

Fungi

What?

Fungi are a group of organisms distinct from plants and animals, they play important roles in decomposition and nutrient cycling. Mushrooms are a well-known type of fungi and edible mushrooms have long formed a part of human diets. Edible mushrooms are a high-quality source of protein, producing protein faster and cheaper than animal and plant proteins. **By dry weight they contain from 18-36% protein** but given their high moisture content (80-90%) as a whole food their protein content is low[59] – see figure 11 below. However, they can be dried and added to food products as a means of enhancing protein or nutritional value[60].

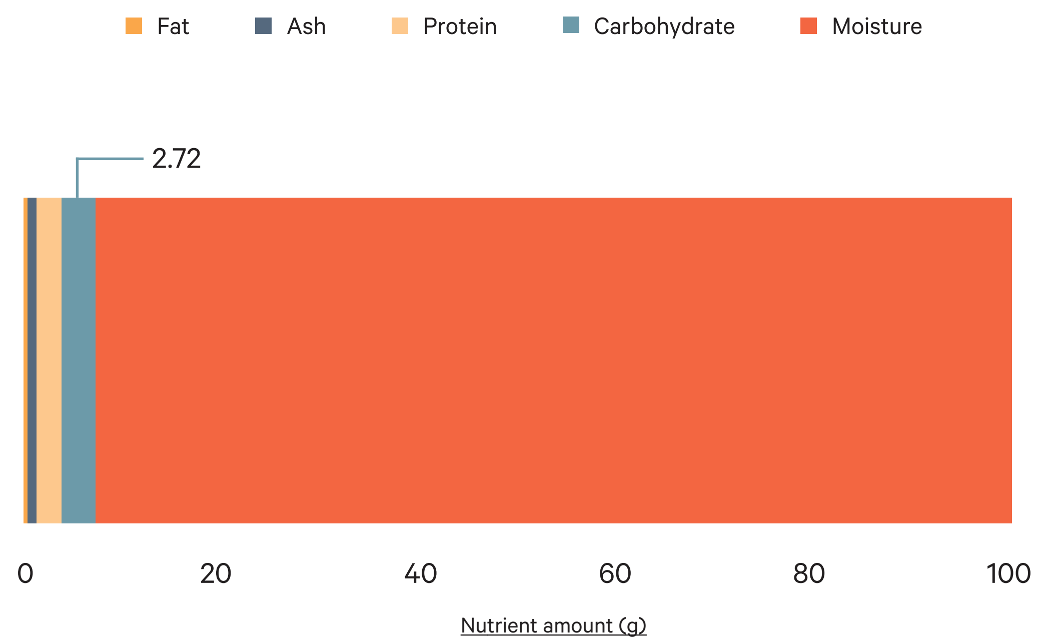


Figure 8. White button mushroom nutrient content per 100g fresh mushrooms

Mycoproteins are a fungal protein composed of the mycelium of certain filamentous fungi – such as Fusarium venenatum. Mycoproteins are produced through fermentation in bioreactors containing required nutrients (primarily glucose) and the resulting biomass is harvested. **The mycelium product is high in protein, low in fat and carbohydrates, and it has a umami flavour and unique meat-like texture that is chewy and fibrous**. This texture is due to the filamentous nature of mycelium, creating a dense and fibrous protein structure. Mycoprotein is also a good source of fibre, vitamins, and minerals, making it a nutritious source of protein that can be consumed with minimal processing or included within meat analogues[61].

Global Context and Development

The global mycoprotein market has been estimated at NZ$916M in 2020 and is expected to nearly double in size by the end of this decade[62]. Quorn is the most well-known company that uses mycoprotein produced via fermentation in its range of products. In 2015, Quorn was acquired by Monde Nissin for NZ$1,322M[63]. Nature's Fynd have raised over NZ$795M and produce a fungal protein that is included in various products from patties to cream cheese. Whilst the Better Meat Co. are a B2B company who raised over NZ$12M in 2020 and produce a mycoprotein from mycelium they have called Rhiza. **The Fungi Protein Association was formed recently and has a variety of members from a range of other companies within this emerging industry**[64].

Current State in Aotearoa New Zealand

Edible mushrooms have been included within plant-based meat substitutes such as Food Nation's 'Magic Mince' and 'Super Sausies'. There are also a range of mushroom-based food products within New Zealand that target applications in the wellness category, not products high in protein.

There are no New Zealand companies producing mycelium-based food products, but Quorn is available for consumer purchase as a meat-alternative food product.

Figure 9. Quorn products available in New Zealand

SWOT Analysis

S

Strengths

- **Product quality:** Considered to have more similar tastes and textures to meat when incorporated in meat analogues.
- **Protein quality:** Considered to be high-quality protein source with a complete amino acid profile.
- **Environmental impact:** Producing mycoproteins is time and resource efficient and thus has a low environmental footprint.
- **Market growth:** The market value for mycoprotein is anticipated to grow from NZ916M in 2020 to almost NZ$1.5B by 2029.

W

Weaknesses

- **Capital investment:** Large-scale production facilities, producing tens of thousands of tonnes of mycelium-based product, could cost hundreds of millions[65].
- **Competition:** Mycelium has been used as a food product for decades, with several well-established international competitors.

O

Opportunities

- **Waste:** Fungi can grow on a range of substrates and so could utilise by-products from other industries and reduce waste.
- **Product innovation:** Mycelium protein could be used as an ingredient in a wide range of food products and could be engineered to have different textures and flavours.
- **Market growth:** There may be an increase in uptake of mycelium protein once these products are cheaper than meat

T

Threats

- **Public perception:** The lack of consumer familiarity with fungal protein could hinder the industry's growth and adoption.
- **Allergen risk:** Concerns have been raised about rare allergic reactions to food products containing mycoprotein and labelling regulations have been enforced in the US and UK[66].
- **Regulatory challenges:** The mycelium protein industry may face regulatory challenges related to food safety, labelling requirements, and other regulations specific to New Zealand.

4
Stars

So What?

- **Mycelium-based protein is a high-quality complete protein**. It also provides a texture that closely resembles meat and contains a range of other nutrients, including vitamins, minerals, and fibre.
- These proteins are produced in an efficient, sustainable, and eco-friendly manner, **requiring fewer resources than other methods**, and has the potential to utilise by-products from other industries creating a more circular economy for the primary industries within New Zealand.
- Whilst mycoprotein has been sold commercially in food products for decades, **a range of new companies are now entering this market** and the market size is expected to double in the next decade.
- Any large capital investment would need a feasibility study completed to understand the economic viability of establishing a production facility within New Zealand.
- The scope of possibilities in the realm of fungi extends beyond high-protein food ingredients such as mycelium. For example, **mushrooms can be utilised in a variety of ways, ranging from whole foods to products that promote health and well-being**.

Insects

What?

Insects are a nutritious and sustainable protein source regularly consumed by tens of millions of people around the world. **There has been an increased interest in insects as a source of protein due to the low demands they place on water, land, feed, and energy consumption**[67]. They are also able to play a role in circular food production systems due to their ability to consume by-products from agriculture as well as organic wastes. However, their consumption is not widely accepted within Western countries due to their novelty as a food source.

Figure 10. Insect food products in New Zealand

Despite this, the United Nations Food and Agricultural Organisation (FAO) recognizes entomophagy as a potential solution to impending food and nutrition shortages[68]. **They can be consumed in various formats, such as freeze-dried or fried, or ground into powder for inclusion in traditional foods (e.g., cricket flour)**.

Global Context and Development

The current global market of insects for human consumption is estimated at just over NZ$1B and is anticipated to grow to almost NZ$1.7B by 2033[69]. This forecast increase is driven by an increasing number of start-up companies in Europe and the promotion of insect protein as a healthy and sustainable choice. **Given the predicted growth, there have been hundreds of millions of dollars invested into startups such as InnovaFeed and Ÿnsect**[70]. In contrast, the Italian government has recently banned the use of flour derived from insects in pizza or pasta[8] as a protectionist move to support its traditional agriculture sector.

Current State in Aotearoa New Zealand

Whilst our consumption of insects as food in New Zealand is limited, **studies have found that New Zealanders are open to trying insects as a food, especially younger people**[71]. They indicated this would be as ingredients in items that resemble familiar foods. However, products containing locally sourced cricket flour entered our domestic market in 2019 but can no longer be found on supermarket shelves. **All insects currently sold for human consumption within New Zealand come from imported insects and are only sold by specialty retailers**.

SWOT Analysis

S

Strengths

- **Nutritional quality:** Insects are a high-quality protein source and contain a range of vitamins, minerals, and fibre.
- **Environment impact:** As an efficient converter of feed, they place low demands on water, land, and energy consumption.
- **International recognition:** Insects have been recognised by the FAO as having to potential to be an important component of sustainable future food systems.

W

Weaknesses

- **Public perception:** Limited consumer acceptance of entomophagy in New Zealand, with studies finding only a possible likelihood of regular inclusion in diets. Further demonstrated by the lack of success of previous products in the domestic market.
- **Know-how:** As a novel industry in New Zealand, there is currently limited expertise and infrastructure in place to support it.

O

Opportunities

- **Waste:** Insects can consume a range of substrates and so could utilise by-products from other industries, including food waste, and so help to reduce waste.
- **Market growth:** The market of insects for human consumption is anticipated to almost double over the next decade and surpass NZ$1.7B.
- **Product innovation:** There is an opportunity for innovation in the development of insect-based food products, such as incorporating them into snacks or protein bars.

T

Threats

- **Regulatory challenges:** The novelty of the industry in New Zealand also means legislation is new, with no specific regulations around insect farming and only three edible insect types approved by FSANZ[71].
- **Competitors:** Consumers are more likely to purchase plant-based burgers over insect protein burgers, despite being dissatisfied with both compared to traditional meat burger[67].

3 Stars

So What?

- **Insects are a nutritious and sustainable protein** source widely consumed in many countries due to their high-quality protein and various nutrients.
- The global market for insects is expanding, but Western attitudes towards insect consumption hinder its growth beyond traditional markets where it is already common practice.
- Efforts to educate consumers about the nutritional benefits and methods of preparation of insects have the potential to promote public awareness and growth of the insect-based food industry in New Zealand.
- **Uncovering new ways to incorporate insects into existing food products or the development of new, innovative insect-based foods may allow insects to appeal to a wider consumer base**. Additionally, marketing insect-based products as a distinct category, rather than a meat substitute, could lower consumer expectations for similar tastes or textures as conventional protein sources[71].
- For an insect-based food industry to develop in New Zealand, it is necessary to address public perception, whilst also improving knowledge about efficient farming techniques and implementing well-defined regulatory frameworks.

Molecular Farming

What?

Molecular farming enables plants to produce animal-based proteins, like casein. This is achieved through genetic engineering, where **plants are modified to produce imitations of specific animal-based proteins** that can be extracted using conventional methods and used as ingredients in food products.

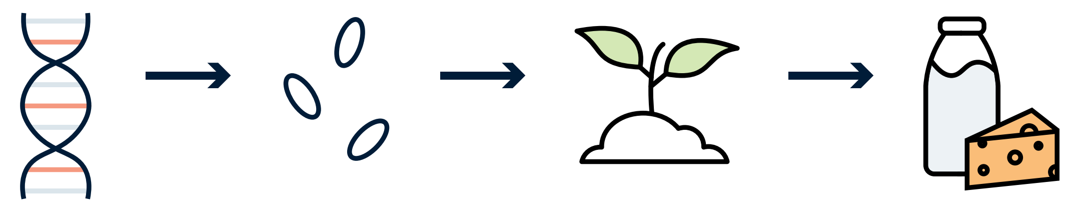


Figure 11. Molecular farming process chart

Molecular farming produces the animal-like proteins within the plant matrix, which offers the opportunity to either purify the target proteins to produce an ingredient similar to a dairy protein isolate, or to produce less refined ingredients that retain other parts of the native plant, such as plant proteins, fibres and micronutrients. It is worth noting that in both cases the overall nutritional value will be different to conventional animal products and instead will contain some of the micro and macronutrient components of the plant material.

Utilising plants to produce proteins is expected to have economic benefits and lead to more available and affordable high-protein products which could positively impact food security around the globe. The Good Food Institute have described molecular farming as a potential "fourth pillar" of alternative proteins, alongside plant-based meat analogues, precision fermentation and cell cultured meat.

The use of genetic engineering in food production raises concerns about the safety, consumer acceptance, and regulation of these products. The FDA recently issued a notice to ensure startups were aware they will require strict allergen management[21]. This is because potential allergens will be being introduced into crops that traditionally do not contain those allergens and thus potential risks around allergens entering the food supply. **Companies in this space are likely to face significant regulatory hurdles across all jurisdictions**.

Global Context and Development

Several startups are actively involved in molecular farming, each with a different approach. Nobell Foods, a US-based company, focuses on cheese production, teaching plants to make casein, and has raised around NZ$120M to date. **Moolec, the first publicly listed company in this space, is based in the UK and aims to produce a range of proteins for cheese and other applications**. Other companies are producing ingredients to be used as cultivated meat growth media.

Current State in Aotearoa New Zealand

Miruku are a company based in New Zealand who produce dairy proteins from oil seed crops, in 2022 they raised NZ$3.8M in seed funding. Whilst headquartered in New Zealand, they have research and development occurring internationally, in Israel and Australia. **New Zealand's regulations do not allow for the commercial production of genetically modified crops domestically**.

SWOT Analysis

S

Strengths

- **Know-how:** New Zealand has a history of expertise related to plant science and food production and we are familiar with producing protein concentrates and isolates, but predominantly from dairy.
- **Product innovation:** New Zealand's food industry is recognised for its innovative approaches in agriculture, farming, and food processing.

W

Weaknesses

- **Regulatory challenges:** New Zealand's current laws related to genetic engineering do not permit the domestic production of food from molecular farming[22].
- **Public perception:** Public apprehension or opposition towards cultivating genetically modified plants could impact the level of acceptance and adoption of molecular farming technology.

O

Opportunities

- **Early adopter:** New Zealand is well placed as one of only a handful of early adopters of this technology.
- **IP potential:** Weightless exports of domestically created IP.
- **Novel applications:** Given molecular farming can theoretically produce any protein, there is the potential to create novel proteins and thus create valuable products.
- **Total utilisation:** Potential to utilise plant biomass following processing, such as for animal feed.

T

Threats

- **Contamination risks:** The risk of gene flow from genetically modified plants to native or non-GMO plants, as well as the effects on biodiversity, are areas of concern that need to be thoroughly addressed.

Other Sources

4 Stars

So What?

- **New Zealand is GMO free** with a strict regulatory environment around genetic engineering and genetic modification of plants or animals. If New Zealand wants to become a player in this space, a wider conversation around the use and regulation of genetic technologies needs to take place.
- Within the current regulations, New Zealand companies would need to consider alternative business models, such as international partnerships, licensing, or intellectual property development.
- New Zealand's **expertise in plant science and protein extraction could be valuabl**e to drive the development of molecular farming technologies, particularly for producing high-value proteins. This could enable the creation of valuable IP and weightless exports.
- Molecular farming has been touted as a fourth pillar in the alternative protein space with many companies focusing on applications related to dairy proteins, **as a dairy-producing nation, New Zealand should keep a close eye on this technology**.

Seaweed

What?

Seaweed is a common name for a group of marine macroalgae, which are multicellular and can grow to large sizes. **Like all algae, they are photosynthetic organisms that utilise sunlight to produce energy**. Seaweeds are found in a variety of marine environments and they play an important role in marine ecosystems as a food source and habitat for marine wildlife.

Seaweed has been consumed as a food by humans for thousands of years. Wider applications of seaweed also exist with extracts used in medicine and other products, such as cosmetics, fertilisers, and pharmaceuticals. However, **their use as a protein source is less often discussed** even though some commonly consumed red seaweeds are known to have **35% protein** (dry weight)[72].

Figure 12. Seaweed based meat analogue product available overseas

Other Sources

Global Context and Development

In 2021, the global seaweed protein industry was worth NZ$875M and is expected to grow to NZ$2.4B by 2030[73]. Seaweed has long been a source of food, such as nori (used in sushi), and more recently in meat analogues by companies such as Akua who produce a variety of burger patties and 'ground meat' products from kelp[74] and Umaro Foods who have created a bacon[75] that utilises seaweed ingredients. **A large driver of this growth is the increased interest in plant-based products**. In 2019, the entire seaweed industry had been estimated to have a value of NZ$21-96B and is expected to surpass NZ$135B by 2026[76]. Thus, the seaweed industry extends well beyond its use in food, as mentioned earlier, which may offer additional opportunities for generating profit. **Most of the global seaweed produced for human consumption comes from aquaculture**, thus, sustainable practices are key to ensuring long-term availability and minimising environmental impacts.

Current State in Aotearoa New Zealand

Recently, a National Science Challenge developed a Seaweed Sector Framework. This is a roadmap into how we could grow our domestic seaweed sector in a way that has economic benefits as well as positive environmental, social, and cultural impacts[77].

A team of researchers from institutes across New Zealand (Cawthron, Riddet, Plant & Food, and the University of Auckland) in collaboration with two research institutes in Singapore are investigating **how to obtain high-value nutritional products from New Zealand Pyropia and Porphyra seaweeds**[78]. While they have achieved a yield of 50% of total protein at lab scale, such yields at pilot scale remain a challenge. **Potential applications include using the seaweed extracts to add the red colour to meat substitutes**, as well as incorporating them into soup-based products and snack bars. Additionally, the researchers are exploring potential bioactive metabolites beyond the above protein applications.

Other Sources

SWOT Analysis

S

Strengths

- **Natural resources:** New Zealand has an extensive coastline and vast ocean territory, along with a diverse array of native and endemic seaweed species.
- **Environmental benefits:** Algae and seaweed protein are sustainable and an eco-friendly protein source that do not require land, freshwater or fertilisers to grow[72].
- **Nutritional quality:** Algae and seaweed proteins are rich in essential amino acids, vitamins, and minerals.
- **Product innovation:** New Zealand's food industry is recognised for its innovative approaches in agriculture, farming, and food processing.

W

Weaknesses

- **Scale up challenges:** Whilst research and industry have demonstrated feasibility of extraction from native species in the lab scaling up remains a challenge.
- **Capital investment:** Whilst no estimates could be found, pricing is likely to be NZ$50-100+M given costs associated with extraction from other produce, such as legumes or grass and leafy greens.
- **Know-how:** Practical knowledge gaps exist in farming native and endemic species, developing high-value products, and managing potential environmental impacts.

O

Opportunities

- **Native species:** New Zealand's native seaweed species may have unique characteristics that could lead to novel food products78 with potential health benefits and differentiation in the market.
- **Market growth:** The global seaweed protein industry is anticipated to more than double within the next decade.
- **Government support:** The New Zealand Government has set a target to grow the aquaculture industry from NZ$600M to NZ$3B by 2035[79] and has supported initiatives towards this.
- **Wider sector possibilities:** Seaweed and algae have the potential to be utilised in other industries alongside food applications, which could provide alternative revenue streams and minimise waste.

T

Threats

- **Regulatory challenges:** The Fisheries Act and Resource Management Act, affect the access of aquaculture ventures to wild seaweed for breeding, and restrict the commercial use of seaweed grown for research purposes.
- **Competition:** Well-established competitors internationally could influence market share within potential export markets.

4 Stars

So What?

- **Seaweed offers a promising opportunity for New Zealand** to enter a growing global protein market due to the abundance of natural resources suited to this industry.
- The scope of possibilities related to seaweed extends beyond high-protein extracts or food products. **The New Zealand government has set a target to grow the aquaculture industry from NZ$600M to a NZ$3B by 2035**[79] and has supported numerous initiatives in this area.
- To promote sustainable aquaculture and support the industry's growth, **the government could consider making changes to the Fisheries Act and Resource Management Act that would facilitate easier access to seaweed resources** while still ensuring their protection and conservation.
- Whilst the New Zealand market is early stage, **there are established markets overseas**. Thus, appropriate market research and a well-thought-out strategy will be crucial to differentiate domestic products to enter specific export markets.
- Any large capex investment into a seaweed protein extraction facility would need a feasibility study completed to understand the economic viability of establishing a seaweed protein processing facility in New Zealand.
- **Further research and development is needed** to address the current knowledge gaps related to large scale seaweed farming in New Zealand and the development of high-value products.
- The use of native seaweed species as novel food products would need to be in collaboration with iwi/Māori.

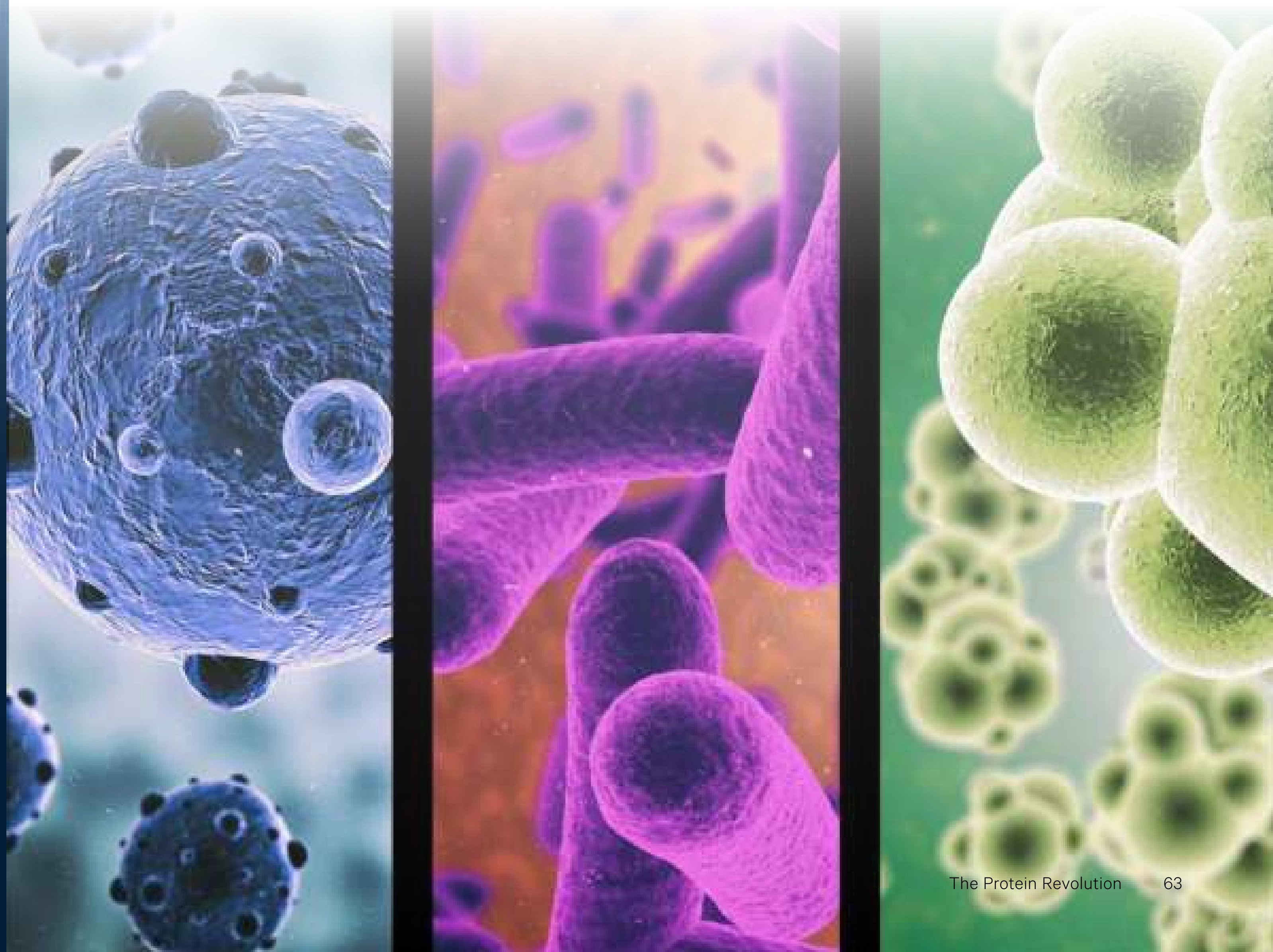
05

Ones to Watch

Air Fermentation

Protein from air is produced using microbes that are fed air, water, and energy to synthesise protein. **The result is a high-protein dry powder, or flour, that due to its texture and flavour can be used as an ingredient in meat alternatives and other food products**. The process is environmentally sustainable requiring minimal land and water use. It has the potential to be carbon negative, as the microbes consume carbon dioxide. However, the overall carbon footprint of protein from air depends on several factors, such as the source of renewable energy, the type of microbes, and the efficiency of the protein extraction process.

The major players are Solar Foods, Air Protein and NovoNutrients. Solar Foods is a Finnish company that has raised over NZ$64M of investment. The main source of renewable energy within their production process is solar power. **Air Protein is based in the USA and claim to be creating the most sustainable meat on the planet**[80]. They have raised over NZ$48M in investment. NovoNutrients are also based in the USA, aiming to transform emissions into protein for food and feed. They have raised US$12M to date. **New Zealand has one early stage start up called Jooules**[81] who state they are creating protein from clean energy and air. They are involved in the current ProVeg Incubator cohort.



Cultured Milk

Cultured milk can be produced through a similar process to that of cell cultured meat (see page 11). **It involves cultivating mammary cells and arranging them in a way that allows for nutrients to be absorbed from a medium on one side of the cell and secretion of milk on the opposing side**[82]. This produces a whole milk product, which is unique when compared to other methods – such as precision fermentation and molecular farming – which only produce a single type of protein from milk or other animal products.

Some of the key start-ups in this space are Biomilq, Me&, and Wilk. Biomilq, a company in the USA create cultured human milk to provide infants with the numerous advantages found in breast milk. According to Crunchbase they have raised NZ$39M in investment. Me& is based in Australia also producing human milk for infants and have raised NZ$4.0M in investment[83]. Wilk is based in Israel and produce both animal and human milk from their respective mammary cells, they are a publicly listed company and have raised NZ$2.4M after an initial public offering according to Crunchbase.

Microalgae

Microalgae are a single-celled type of algae which, like all algae, utilise photosynthesis to produce energy. **Spirulina and chlorella are well known types of microalgae that have become more common in recent decades as a 'superfood' or dietary supplement**. The use of algae to date is generally as a supplement, or other high value nutrition product, but **their potential as a high protein food source has also gained recent attention**[84].

Some companies producing protein from microalgae include Brevel and NewFish. Brevel are an Israeli-based startup who are developing microalgae-based proteins and other functional products and have raised NZ$18.9M, according to CrunchBase. **NewFish are a New Zealand based startup who have raised NZ$1.3M, they use microalgae fermentation to produce a concentrated protein powder that has functionality as a food ingredient**. They are collaborating with the Cawthron Institute to identify and grow native microalgae strains suitable for their applications[85].

06

Food for thought

From the outset the intention of this report was to help New Zealand accelerate its decision-making regarding how (or if) it chooses to take part in this rapidly moving novel agrifood sector. After undertaking this analysis, **the primary decision that needs to be made, is an across-the-board commitment to diversify into the emerging protein sector**. Such commitment would ensure that **appropriate scaffolding was built around the sector** to give it the best opportunity to succeed. Scaffolding in the way of **government support is critical for the industry** through appropriate levels of funding, incentives to farmers and growers, scientists, innovators, and entrepreneurs, and suitable regulation that supports an emerging industry.

Assuming a commitment to diversification is made, any investment in the emerging protein sector should be targeted to those sources where New Zealanders could benefit, or New Zealand would have a competitive advantage. Based on the information presented in this report, **there are four emerging protein sources that New Zealand may be best placed to explore further or advance***:

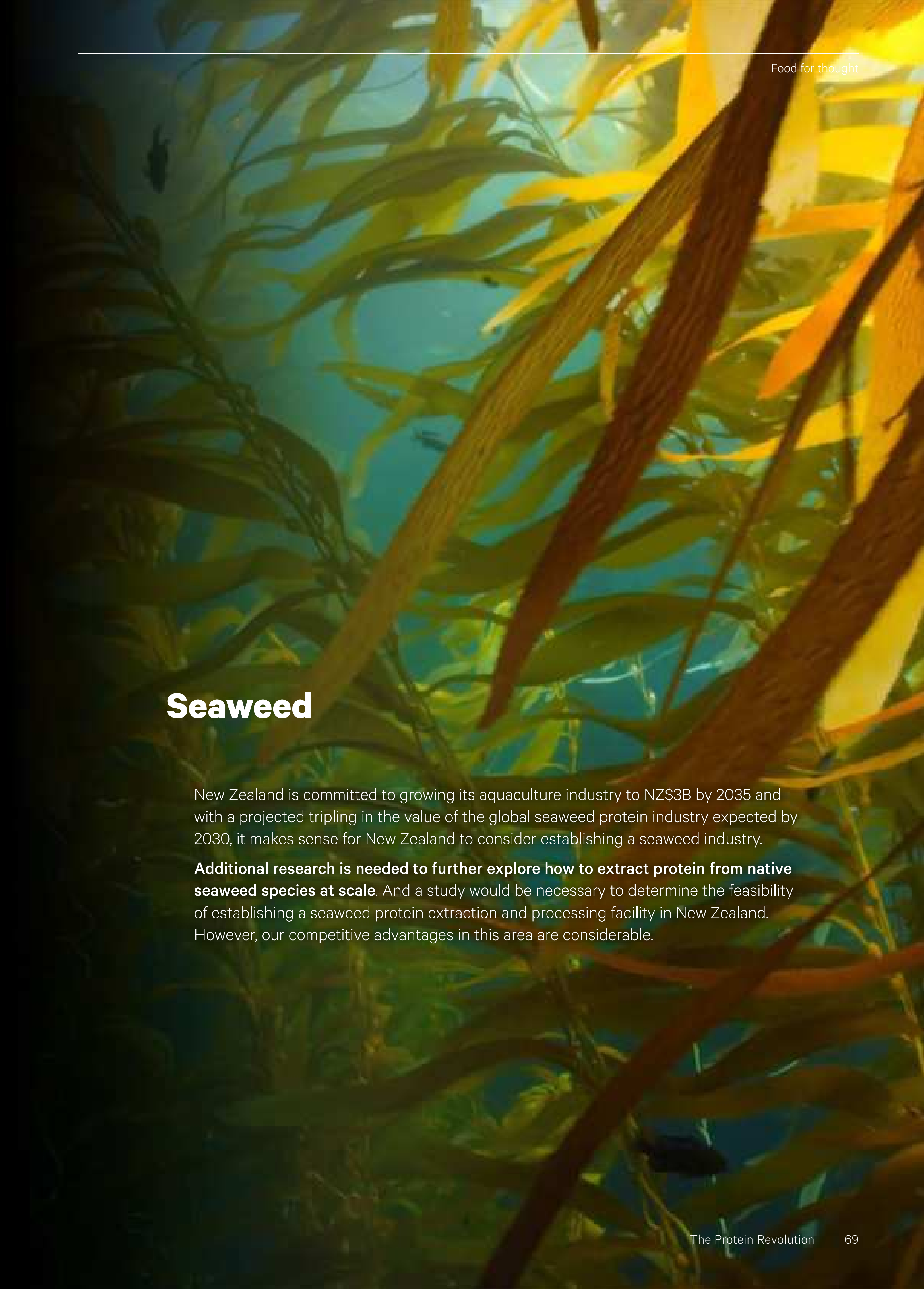
* When it comes to protein diversification, it is important to acknowledge that there is no single perfect option available. Every potential avenue for diversification comes with its own set of risks and considerations. Thus, while we consider these to be the most well suited, there is no guarantee of success.

Hemp

New Zealand's temperate climate is well suited to growing hemp, and it thrives in many regions. Combined with deep expertise in plant science and food production, there is potential to produce hemp at scale. As a nutrient-rich source of protein, **hemp seed has value as whole food source and a high-value food ingredient**. It has a lower water footprint and requires less pesticides compared to other crops, while its deep roots contribute to soil health improvement and erosion prevention. This all means **it is well positioned to compete alongside soy, pea, and fava bean protein as a major plant-based protein ingredient** in a market expected to have rapid growth in the coming years.

Processing facilities currently exist across New Zealand, but further investment in facilities and specialised equipment would help to expand cultivation areas. **Targeted research** on the most suitable or novel strains for local conditions and food production could help to unlock the crop's full potential as a food source.

However, a 'Hemp as Food Industry Strategy' and consumer education programme would be needed to manage the risks related to competition within the established international hemp market and the distorted consumer perception about hemp as a food source, respectively.



Seaweed

New Zealand is committed to growing its aquaculture industry to NZ$3B by 2035 and with a projected tripling in the value of the global seaweed protein industry expected by 2030, it makes sense for New Zealand to consider establishing a seaweed industry.

Additional research is needed to further explore how to extract protein from native seaweed species at scale. And a study would be necessary to determine the feasibility of establishing a seaweed protein extraction and processing facility in New Zealand. However, our competitive advantages in this area are considerable.

Grass and Leafy Greens

New Zealand's deep knowledge and experience in cultivating forage crops uniquely positions it as an ideal processor of protein-rich food ingredients derived from grass and leafy greens. Protein extracted from these crops has excellent properties that make it a suitable high-protein ingredient with an array of high-value food applications. It can also help deliver climate outcomes. This gives it the **potential to compete with other major plant-based proteins** in a rapidly growing market.

Whilst still at an early stage of development, **New Zealand has an opportunity to file intellectual property in this area, providing plausible future weightless exports**. The feasibility of establishing commercial scale extraction facilities would need to be considered and incentivisation may be required to encourage repurposing of land for growing these crops.

Fungi

Mycelium-based protein is high quality and closely resembles the texture of meat. It can be produced in an efficient and sustainable manner, whilst requiring less resources than many other methods. **With the potential to utilise by-products from other primary industries, this could complement and enhance sustainable resource utilisation and circular food production practices**.

The market is expected to grow, and international companies have demonstrated success in similar western markets. However, t**here is a lack of consumer familiarity with mycoprotein**, and challenges may exist surrounding regulation of potentially novel food products. Despite the absence of New Zealand companies currently producing mycelium-based protein, **this underexplored yet potentially lucrative sector warrants consideration**.

07

Appendix

Appendix One: Limitations of the Report

While every effort has been made to ensure the accuracy of the information provided throughout this report, it should be noted that limitations exist, specifically:

- The information provided reflects a specific point in time. The desktop review took place from February to June of 2023. It is important to note that due to the rapid pace of change in this sector, there may have been subsequent additions or changes that have not been included within this report.
- The report is based solely on publicly available sources of information and some discussions with industry stakeholders. It is worth noting that companies and other entities within the sector may possess additional information that is not publicly accessible or is considered intellectual property and so could not be included within this report.
- Much of the available information originates from companies creating the emerging protein sources that have a personal stake in the success of the specific emerging protein source. Other information, often with negative perceptions of emerging protein sources, is presented by industries that could face disruption if the emerging protein sources were successfully produced at scale to service the global or domestic market. This makes it challenging to determine how much weight to put on any single perspective.
- This report is one piece of the puzzle and broader challenges exist within the food system. Issues such as climate change, food waste, and access to affordable, nutritious food must be addressed alongside the diversification of our protein sources.

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Appendix Three: Ratings Rubric and Scores

Rating Area	Definition	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Competition	The level of market saturation, opportunities for new entrants, and the impact of export costs on market viability.	Market is saturated with no space for new entrants and/or prohibitive export costs.	Limited room in the market for new entrants and/or export costs will create challenges.	Potential room in the market for new entrants and/or export costs are reasonable.	Some room in the market for new entrants and export costs are reasonable.	Considerable room in the market for new entrants and export costs are acceptable.
Regulations	Rules and standards that impact production, processing, and sale.	The regulatory environment prohibits the production or sale.	The regulatory environment will create challenges in production or sale.	The regulatory environment will have limited impact on the production or sale.	Minimal impacts of the current regulatory environment on production or sale.	Only minor, if any, impacts of current regulatory environment on production or sale.
Natural Resources	The environmental suitability to produce the inputs for the protein source.	New Zealand lacks the natural resources to produce the required inputs.	New Zealand's natural resources have limited capability to produce the required inputs.	New Zealand's natural resources have some capability to produce the required inputs.	New Zealand's natural resources have considerable capability to produce the required inputs.	New Zealand's natural resources have significant capability to produce the required inputs.
Know How	Workforce experienced in or knowledgeable about the production and processing methods of the protein source.	Domestic workforce has no experience or knowledge in the production or processing methods of the protein source.	Domestic workforce has limited experience or knowledge in the production or processing methods of the protein source.	Domestic workforce has modest experience or knowledge in the production or processing methods of the protein source.	Domestic workforce has strong experience or knowledge in the production or processing methods of the protein source.	Domestic workforce has extensive experience or knowledge in the production or processing methods of the protein source.

Table 1. Ratings Rubric

	Emerging Protein Source	Competition	Regulations	Natural Resources	Know How	Rating
Lab-Based Soruces	**Cell Cultured Meat**	3	1	1	2	2 Star
	Molecular Farming	4	1	4	4	4 Star
	Precision Fermentation	2	1	1	3	2 Star
Plant-Based Soruces	**Grass and Leafy Greens**	5	2	5	4	4 Star
	Hemp	4	3	5	4	4 Star
	Legumes	2	5	5	4	4 Star
	Oats	2	5	5	4	4 Star
Other Sources	**Fungi**	4	2	5	2	4 Star
	Insects	3	2	3	2	3 Star
	Seaweed	4	2	5	2	4 Star

Table 2. Ratings for Emerging Protein Sources

Appendix Four: Stakeholders Engaged in the Report

In publishing this report, FoodHQ has liaised with several stakeholders across the emerging protein sector. These are listed below for transparency:

FoodHQ Partners:
AgResearch
Fonterra
Massey University
Palmerston North City Council
Plant and Food Research
The Riddet Institute

Industry/Product Development:
HempNZ
Meadow Mushrooms/Food Nation
Sustainable Foods Limited

Industry Bodies:
AgMardt
ANZSA
Foundation for Arable Research
New Zealand Trade and Enterprise

Policy and Government:
Climate Change Commission
Ministry for Business Innovation and Employment
Ministry for Primary Industries

Appendix Five: Glossary

Amino acids
Small molecules that serve as the fundamental building blocks, or subunits, of proteins.

Business to business (B2B)
Commercial transactions or interactions between two businesses or organisations, rather than directly between a business and a consumer.

Cell culture (or cultivation)
The process by which cells, such as animal cells from cattle or sheep, are grown in an artificial environment.

Cell culture medium
A solution used to provide essential nutrients and growth factors necessary to support the growth and proliferation of cells in vitro.

Cell lines
A population of cells derived from a single cell and grown in a laboratory setting that can be used for a variety of research or industrial purposes.

Cereal
A type of grass that is grown for its edible grains or seeds, they are a staple food source across the world.

Circular food production
A system of producing food that emphasises using renewable resources, reducing wastes, and repurposing by-products for further food production.

Complete protein
A protein that contains all the essential amino acids in the amounts they are required by the human body.

Essential amino acids
A group of amino acids that the human body cannot produce on its own, or from other amino acids, and must therefore be consumed in the diet.

Entomophagy
The practice of humans consuming insects as food.

Feasibility study
A preliminary analysis conducted to assess the practicality and viability of a proposed project or idea, typically examining factors such as financial, technical, and logistical considerations.

Feedstock
The raw materials or substances that are used as a starting point in a production process, such as sugar in the precision fermentation of protein molecules.

Foetal bovine serum (FBS)
A nutrient-rich liquid obtained from foetal blood of cows, commonly used as a growth medium supplement in the production of cell cultured meat.

Food and Agriculture Organisation (FAO)
An agency of the United Nations that aims to eliminate hunger, malnutrition, and poverty through the sustainable development of agriculture, fisheries, and forestry.

Food and Drug Administration (FDA)
A United States government agency responsible for regulating food, drugs, and other consumer products.

Food Standards Australia New Zealand (FSANZ)
A bi-national government agency responsible for developing and maintaining food standards for Australia and New Zealand.

Forage crops
Plants grown specifically for livestock to graze or forage, providing these animals with a source of food and nutrients.

Greenhouse gases (GHG)
Gases, such as carbon dioxide, methane, and nitrous oxide, that trap heat in the Earth's atmosphere.

Growth factors
Proteins or hormones that stimulate the growth, division, and differentiation of cells in a specific way.

Hemp (or industrial hemp)
A strain of the Cannabis sativa plant species that is grown specifically for industrial use, it contains very low levels of the psychoactive compound THC.

Legumes
Plants in the family Fabaceae, they are known by their edible seeds that are high in protein and dietary fibre.

Meat analogue
Also known as plant-based meat or meat substitute, this refers to a food product made without animal ingredients – typically plant-based – that mimics the taste, texture, and appearance of animal meat.

Megatonne (Mt)
A metric unit equivalent to 1 million tonnes.

Mycelium
The root-like network of fungal cells that grows within a substrate and is responsible for absorbing nutrients and supporting the growth of the fungus.

Nitrate losses
The loss of nitrogen in the form of nitrate from agricultural soils through leaching or runoff, it can have negative environmental impacts including water pollution and contribute to greenhouse gas emissions.

Nutritional composition
The different nutrients and beneficial substances found in food or dietary supplements. These can include carbohydrates, proteins, fats, vitamins, minerals, and other compounds that provide nourishment.

Photosynthesis
The process by which green plants, and some other organisms such as algae, use sunlight to produce energy in the form of glucose.

Pilot scale
A small-scale version of a production system or process used to test and enhance new technologies or products before large-scale commercialisation.

Plant-based
Refers to a food or product derived from plants, including fruits, vegetables, grains, legumes, nuts, and seeds, and does not contain any animal-derived ingredients.

Precision fermentation
A method of producing protein or other compounds using microorganisms, such as yeast, with precise control over the final product's properties.

Protein
A macromolecule composed of amino acids that plays an essential role in various biological processes, including the growth and repair of tissues, enzyme and hormone production, and immune system function.

Protein concentrate
A type of food ingredient made by removing a portion of non-protein components (such as water, fibre, and minerals) from a protein-rich food source, resulting in a product that contains a higher percentage of protein than the original food.

Protein extraction
Involves utilising physical, chemical, or biological methods to separate protein molecules from a complex mixture of substances, such as cells, tissues, or food sources.

Research and development (R&D)
Activities and processes that companies and organisations undertake to innovate and create new or improved products, services, or technologies.

Rubisco
A plant protein that plays a crucial role in photosynthesis by fixing carbon dioxide into organic molecules.

Umami
A taste sensation often described as savoury or meaty.