MEAT RE-IMAGINED

THE GLOBAL EMERGENCE OF ALTERNATIVE PROTEINS
- WHAT DOES IT MEAN FOR AUSTRALIA?
FOREWORD

Our food system is undergoing its greatest transformation of the last century. We are facing the prospect of a global population 10 billion strong in the age of potentially devastating climatic shifts and severe public health challenges. Traditional methods of production are insufficient to meet the challenges and demands confronting us. New technologies offer the prospect of producing nutritious, sustainable foods to feed a hungry world.

The rise of alternative proteins, from humble and ancient beginnings to the modern technological advances of plant-based meat alternatives and cellular agriculture, has enormous potential as a tool for addressing today’s food system challenges – especially given the extent to which these innovations are being embraced by consumers of all dietary habits.

To date, leading researchers and companies in the U.S., Europe and Asia have forged ahead with new production processes and products, while Australia has largely remained an observer. This paper intends to kick-start a distinctly Australian discussion on alternative proteins that considers our unique consumer base, skills, production systems and economy.

The emergent alternative protein industry is complementary to Australia’s strong agricultural tradition – simultaneously increasing sustainability and system efficiency, and addressing public health challenges. Investments by the world’s largest meat companies into alternative proteins, and their re-positioning as ‘protein’ providers, signals how conventional agriculture and alternative proteins can coexist, inviting new cooperative opportunities such as supplying primary inputs and producing new crop varieties.

Australia’s globally trusted brand is synonymous with safe, high-quality food – a testament to the integrity of our production systems and manufacturing capabilities. With a growing international consumer base seeking safe, sustainable, healthy food, Australia is ideally placed to leverage our wealth of research and manufacturing capabilities as well as the production and marketing expertise of the conventional protein sector to rapidly scale-up.

A diversified protein sector offers Australia new industrial opportunities and job creation across a variety of fields, the implications and quantum of which this paper identifies as an area in need of further research. Government has a role to play by providing support and countering the siren-calls of those intent on protecting the status-quo with positive, progressive policy. Alternative proteins are a reality; Australia now faces the choice of sitting on the side-lines or becoming a sectoral leader.

To achieve success, the scientific, business, government and conventional food and manufacturing sectors must work collaboratively to overcome challenges and fulfil the potential of a new and vibrant industry.

I am grateful to the authors and researchers who devoted so much time and effort to compile this paper, particularly Sam Lawrence, Food Frontier’s Managing Director, agricultural specialist and the paper’s principal author. While not exhaustive, the paper specifically focuses on the three main pathways of plant-based, cell-based and hybrid products as realistic, healthier, sustainable and scalable options to feed our growing population.

I would like to acknowledge and thank the Lord Mayor’s Charitable Foundation whose generous support made this project possible.

Thomas King

CEO, Food Frontier
Young Australian of the Year VIC 2015

Funded by
Food Frontier is Australia and New Zealand's leading think tank and industry accelerator for plant-based meat alternatives and cell-based meat. Funded by philanthropy, Food Frontier is proudly independent.

We believe food innovation is critical to feeding the growing global population in coming decades. By driving science-based solutions to the need and demand for sustainable, healthier proteins, we are working to create a more diversified, efficient and future-proof food supply that is good for people, great for business and better for the planet.

Globally renowned for world-class food research, production, and exports, Australia and New Zealand are exceptionally well-placed to become the Asia Pacific’s leaders of the rapidly emerging alternative protein sector.

Through research, advocacy, consulting and events, Food Frontier advises and connects stakeholders across the supply chain, from agriculture and science to government and business. We support existing and emerging leaders to capitalise on the opportunities to create and supply plant-based and cell-based meat in the world’s most populous region, where diversification is most urgently needed.

Our Approach

**Activating Development** of, and investment in, new applications for plant proteins and cellular agriculture by working with scientists, entrepreneurs and investors.

**Accelerating Supply** of new products to market by working with food businesses, industry groups and regulators.

**Advocating Adoption** of new choices within the market by working with food outlets, consumers and the media.

**Paper Review Panel**

Food Frontier would like to thank our exceptional review panelists for their insights.

- **Angeline Achariya**
  CEO, Monash Food Innovation Centre

- **Dr David Welch**
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Our ability to meet the increasing protein demands of the world’s growing population is reaching a critical inflection point. Leading authorities have warned that our current food production systems will fail to sustainably feed the world without urgent changes.¹,²

Today’s methods of protein production have far-reaching implications, from threats to food safety and security, to environmental degradation and dwindling natural resources – threats from which Australia is not immune.

Rapidly emerging technologies in plant-based meat alternatives, cell-based meats and hybrid proteins are offering innovative solutions. If properly harnessed by industry and supported by government, these foods promise new ways to meet consumer demand for familiar products, while increasing the sustainability of our food systems.
Today’s food system feeds a global population of 7.6 billion,³ and is rapidly approaching its productive limits. The food system of 2050 will need to feed a projected population of 9.8 billion,⁴ with estimates that food demand will rise by more than 50 percent, and demand for animal-based foods by nearly 70 percent.⁵

Globally, meat production increased four to five fold since 1961 to meet the demands of a growing population¹⁰ and increasingly affluent consumers in developing and middle-income nations such as China, India and Brazil who are consuming greater amounts of meat.¹¹ There is simply not enough productive land left to meet the increasing global population’s protein needs without a significant shift in production efficiency.¹²,¹³ Today, raising livestock requires about 80 percent of the world’s agricultural land¹⁴ and produces just 18 percent of the world’s calories.¹⁵ A third of global croplands are currently used to grow feed for farm animals, while more than a quarter of the planet’s habitable land is used for livestock grazing.¹⁶ The pressure to innovate is falling on the shoulders of industry to find more sustainable methods of protein production, and governments to encourage changes in consumption patterns.

**Figure 1. Global meat consumption trend.**

Australians consumed approximately 110 kilograms of meat per person in 2015 — more than three times the global average (excluding seafood).⁶ Australians eat more than four times the global per capita average of beef and veal,¹⁷ rivaling countries like Brazil and the U.S.⁸ Annual chicken consumption has also skyrocketed in Australia, growing tenfold from 4.6 kilograms per person in 1965 to 47 kilograms in 2016.³
Excess meat consumption and current production have significant effects on human health, livelihoods and the economy. Meat thus poses a special challenge to the future development of the global food system.” 17

— WORLD ECONOMIC FORUM
Nearly a third of the water used in agriculture globally is used to produce animal-based products, while manure runoff from intensive farming operations and pesticide runoff from animal feed-crops are major causes of freshwater contamination. Increased levels of nutrients from manure runoff have led to algal blooms, and contribute to oceanic ‘dead zones’ where oxygen levels are too low for some marine life to survive. The global scale of animal agriculture is reflected in a recent report examining the biomass distribution on Earth published in the Proceedings of the National Academy of Sciences in 2018. The report found that farmed poultry now makes up 70 percent of all bird life on the planet, with just 30 percent being wild. The story for mammals is even more stark, with 60 percent of all mammals on Earth being livestock, 36 percent humans and just 4 percent wild mammals.

Animal agriculture is a leading cause of deforestation, land degradation, biodiversity loss, and habitat destruction worldwide. In the Australian context, from 2013–2015, livestock grazing accounted for 91 percent of deforestation in Queensland, which diminished the habitat of native species including the koala. Across the border, the New South Wales Department of Primary Industries (NSW DPI) highlighted the critical importance and challenge of preserving high-quality water sources in Australia – a problem exacerbated by many practices common in conventional animal agriculture. Despite the recommendations by NSW DPI, no formal policies have been created to guide improvements in resource use and preservation.

International commentators from scientists to business leaders are beginning to fundamentally question the efficiency of conventional animal agriculture. In the context of U.S. farming, it’s estimated that a chicken must be fed eight calories of feed to generate one calorie of chicken meat. In the case of beef, 34 calories of feed are required to produce one calorie of meat. While the Australian agricultural system is significantly different to that of the U.S., these estimates serve to highlight the fact that every kilogram of meat produced from an animal represents a significant loss of calories from the food system.

It is widely recognised that conventional animal agriculture has an outsized impact on atmospheric greenhouse gases. A Food and Agriculture Organization report from 2013 estimated that livestock accounts for 14.5 percent of all human-induced greenhouse gas emissions. Beef in particular has a major impact, with the World Resources Institute stating that if cattle were able to form their own nation, they would rank third behind China and the United States on the list of the world’s largest greenhouse gas emitters. According to leading international policy institute Chatham House, it is unlikely that world governments will be able to meet the goals laid out in the Paris Climate Accord without addressing emissions from animal agriculture.

For every 10 kilograms of grain...we get 1 kilogram of beef in return. The caloric kick-back is just too low to feed a growing world population.” — BILL GATES
PUBLIC HEALTH CHALLENGES

Current meat consumption levels and methods of production pose public health challenges, particularly in the context of intensive animal agriculture.

On a global level, widespread use of antibiotics in intensive animal agriculture production is directly linked with issues of rising antibiotic resistance around the world. The World Health Organization estimates that in some countries “80% of total consumption of medically important antibiotics is in the animal sector.” Further, the potential of breeding new zoonotic diseases within high-density farm environments – such as swine and avian influenza – presents a significant public health risk. Additionally, faecal bacteria contamination during meat processing is among the leading causes of foodborne illnesses in consumers. In the local Australian context, a study by Food Standards Australia and New Zealand found that more than four in five portions of raw chicken were contaminated with campylobacter bacteria, and that nearly two in five were contaminated with salmonella.

A number of peer-reviewed studies from sources including the National Institutes of Health, the World Health Organization, and Harvard School of Public Health, link high levels of conventional meat consumption to diseases including cardiovascular disease, type 2 diabetes, and colorectal cancer, partly due to risk factors including LDL cholesterol and saturated fat. These diseases are among the leading causes of death in Australia, and could be reduced through greater adoption of plant-based foods.
Despite the challenges presented by conventional meat production, meat remains a large part of diets and economies worldwide. In 2015, Australia was the world’s largest exporter of beef and veal, with the red meat industry alone accounting for approximately 440,000 direct and indirect jobs across the country. Governments and industry will need to understand and implement new models of production that mitigate or eliminate the health, environmental, and economic challenges posed by the current system. These may include efficiency and sustainability improvements to existing systems, however, research has shown this alone will not be sufficient, warranting solutions that don’t rely on animal agriculture.

Data shows that an increasing number of consumers are demanding alternatives to conventional meat. As most consumers’ food choices are driven by taste, price and convenience, a growing number of companies are producing affordable and accessible meat alternatives that offer the sensory experience that consumers are accustomed to in meat. Groups of scientists and entrepreneurs around the world are demonstrating that food science, nature and human ingenuity can produce popular foods – from burgers to dumplings – without reliance on animal agriculture.

Aggregate growth in the consumption of conventional meat is expected to slow, according to McKinsey & Company, to 1-1.5 percent per year overall growth. Conversely, consumer and investor interest in alternative proteins is rising with plant-based product launches more than doubling in the past five years. Consumers are increasingly embracing a ‘flexitarian’ diet, which places an emphasis on consuming plants without eliminating animal protein entirely. Younger generations in particular are leading the trend toward reducing conventional meat consumption, citing their significant buying power and citing health and environmental concerns as primary motivators. Euromonitor ranked Australia as the most favorable market for plant-based products, citing a large population of millennials, and high rates of plant-based eating. Market research has predicted a combined annual growth rate of 7.7 percent globally and 9.4 percent in Asia between 2018 and 2025 for ‘meat substitutes.’

This paper seeks to provide insights on the most promising growth areas across a range of alternative protein sources, including the context necessary for Australian innovators and policy makers to determine the most effective paths toward a sustainable food future.

Plant-based meat alternatives and cell-based meat represent viable alternatives to conventional meat. Other forms of alternative protein such as algae and insects, are being pursued as protein supplements, however functional limitations and cultural norms restrict their utility as realistic meat alternatives. Consequently, this paper focuses primarily on plant-based meat alternatives and cell-based meat as the two principal meat alternative categories.
PLANT-BASED MEAT ALTERNATIVES

BACKGROUND

Innovators in today’s market for plant-based meat alternatives are redefining what it means to eat meat. New options that replicate the familiar textures and flavours of conventional meat are encouraging more consumers to move plant-based meat alternatives to the centre of the plate.

Plant-based meat alternatives come in a variety of forms, from whole-food meat mimics such as ‘pulled’ jackfruit and fermentation-based products such as those made by Quorn, to technologically advanced plant-based meats including the Beyond Burger and Impossible Burger.

Though the plant-based trend may be considered relatively modern, plant-based meat alternatives such as tofu and seitan have been a part of dietary habits for centuries. There is evidence that tofu was specifically promoted as ‘mock lamb chops’ as early as 965CE. The 20th century saw the development of plant-based meat alternatives including Protose, a seitan-like meat alternative. Following the Second World War, significant advances in production and packaging technology contributed to the development of products based on plant protein isolates, concentrates and textured proteins.

Today, technology is enabling the development of a new generation of plant-based meats that appeal to mainstream consumers. These products are marketed toward omnivores and aim to mimic the sensory experience of eating conventional meat. The consumer response to this emerging category has been significant, with demand for some products now outpacing supply. Restaurant chains around the world are putting next generation plant-based meats on the menu, grocery chains are stocking them in the meat aisle alongside conventional meat, and conventional meat companies are launching and acquiring plant-based brands at a frenetic pace.

The consumer shift towards plant-based meat alternatives and plant-based foods more generally is happening at a moment when industry incumbents and governments are seeking to mitigate some of the negative externalities of conventional meat production.
The growth of the plant-based meat alternatives sector is reflective of a number of broader social and consumer trends occurring globally. Increasing awareness about the health and sustainability implications of our diets, and a growing desire for convenience, are significant factors in the rising demand for plant-based meat alternatives. The entry of new plant-based meat products and brands into the market is expected to significantly diversify protein options available to consumers, much like plant-based milk products have offered choices beyond conventional dairy.

Growth

In 2018, the value of the global plant-based meat alternatives market was estimated at US$4.33B. Market research firms are projecting record growth in the plant protein sector in 2019 and beyond, with Lux Research estimating a doubling in demand for alternative proteins by 2024. Quorn, a veteran alternative protein company, has announced it is on track to be a billion-dollar business by 2027. Although plant-based meats still comprise less than one percent of the global meat market, the sector has seen remarkable levels of year-on-year growth, registering a 24 percent increase in sales from June 2017-2018 alone. Comparably, Nielsen reports overall plant-based food and beverages sales growth of 14.7 percent in the U.S. from 2016-2017.

Some niche products have shown tremendous growth, including jackfruit-containing prepared foods, which grew 377 percent from 2016-2017. Assuming plant-based meats continue to advance in terms of taste, flavour and health benefits, CB Insights postulates that “we could see direct competitors to meat incumbent brands across virtually all frozen and prepared food categories.”

Figure 2. Growth of plant-based meats and animal meats in U.S retail market.

*52 weeks dollar sales ending August 2017. **52 weeks dollar sales ending June 2018. PBFA-commissioned data from Nielsen
Marketing

Many of the companies behind popular plant-based meats are utilising forward-thinking marketing to appeal to a far broader consumer base than vegetarians and vegans. By balancing messaging and imagery to highlight taste, experience, health and sustainability, and by putting an emphasis on innovation, new plant-based meats have largely overcome previous associations with dietary restriction and flavour or textural deficiencies.

Two companies – Beyond Meat and Impossible Foods – exemplify this approach to marketing. Beyond Meat features popular athletes in its advertising, emphasising the performance and health benefits of its products. The start-up couples this approach with appeals to sustainability and naturalness and highlights its “free-from” status with regard to soy, gluten, and cholesterol.

Taking a distinctly more Silicon-Valley approach, Impossible Foods has successfully positioned its plant-based meats as high-tech advancements. By embracing novelty and an iPhone-like product release pattern, Impossible Foods has earned itself a notable amount of publicity and social media attention, thus generating significant public interest – particularly from millennials. In January 2019, the company presented its Impossible Burger 2.0 at the Consumer Electronics Show in Las Vegas, where it received a highly enthusiastic reception and was awarded the “Top Tech of 2019” by tech publisher Digital Trends. Consumer research conducted by Impossible Foods has indicated that approximately 70 percent of their customers eat conventional meat.

We’re not going to solve this problem by pleading with consumers to eat beans and tofu instead of meat and fish ... we're making meat for uncompromising meat lovers, but with a fraction of the environmental impact.”

— Pat Brown, Impossible Foods CEO
Product Availability

Across the world, plant-based meats are rapidly expanding into the mainstream. According to Shama Lee, founder and CEO of New Zealand’s Sunfed Meats, “we’ve got a good problem, which is that we can’t meet demand.” Sunfed Meats launched its plant-based chicken alternative in Progressive Enterprises and Foodstuffs Markets in New Zealand in 2017, selling out within days of its debut.24

In the Australian fast food sector, Hungry Jack’s (whose menu already features a vegetarian burger) began trialling a plant-based meat burger called ‘Kinda Meat Burger’ in the Australian Capital Territory and Goulburn25 (regional New South Wales) in early 2019, at a comparable price to conventional beef burgers. White Castle, the oldest fast-food burger chain in the U.S., sells a slider made by Impossible Foods for US$1.99,26 while retailers such as Tesco in the United Kingdom now stock Beyond Meat burgers and have launched fully plant-based products developed by in-house innovation centers.27

Placement inside meat cases within supermarkets has proven to be a strong accelerator for sales of plant-based meats. Figures from one of the largest conventional retailers in the US reveal that out of all its grocery stores in southern California, the Beyond Burger was the number-one-selling burger patty in the meat case over a five-week period.28 The Beyond Burger is now available at more than 20,000 grocery stores and in more than 11,000 restaurants,29 including throughout Australia at retailers such as Coles and IGA.

86% of U.S. consumers who regularly consume plant-based alternatives do not consider themselves vegetarian or vegan.

Impossible Foods production line in Oakland, California
Consumer Trends

The percentage of vegetarians in Australia is on the rise, increasing from 9.7 percent in 2012 to 11.2 percent in 2016, and jumping by 30 percent in NSW. While vegetarians and vegans will naturally be early adopters of plant-based meats, these consumers are not the primary target for many plant-based meat companies. Consumers actively seeking to reduce their consumption of conventional meat are more likely to purchase plant-based meats. Of U.S. consumers who regularly consume plant-based meat alternatives, 86 percent do not consider themselves vegetarian or vegan.

Beyond Meat, Impossible Foods and other start-ups are directly targeting the most valuable market for plant-based meats: omnivorous millennials. This approach appears to be working, with Beyond Meat’s sales increasing 70 percent in 2018. More than half of U.S. non-millennials eat meat alternatives, rising to nearly eight-in-ten millennials. Almost one-third of millennials report that they are trying to eat a more plant-based diet.

Costs

Plant-based meats are, in some instances, already achieving price parity with conventionally produced equivalents; however, many are yet to become competitive with conventional meat in terms of scale and cost.

Figure 3. Retail price comparison of plant-based meat and equivalent, specialty conventional meat products in Australia – Woolworths Supermarket (online at woolworths.com.au) and Hungry Jack’s fast food outlet (ACT).
If we are not aware of it and participating in our own disruption, we basically deserve what we get.”

— TOM MASTROBUONI, CHIEF FINANCIAL OFFICER, TYSON VENTURES

INVESTMENT

The pace and magnitude of consumer adoption of plant-based meats is evidence of latent demand. However, continued growth in the sector is largely contingent on funding to scale production and distribution.

Investors have shown significant and increasing interest in the market for plant-based meats. In 2016, Tyson Foods, one of the largest meat processing companies in the world, launched a US$150 million venture fund to support “breakthrough technologies, business models and products to sustainably feed the growing world population.” The fund’s first action was to purchase a stake in Beyond Meat. General Mills’ venture capital arm soon followed suit with its own investment in Beyond Meat. Former McDonald’s CEO Don Thompson’s venture capital fund, Cleveland Avenue, also counts Beyond Meat among its portfolio brands. Tyson Foods has even announced its intention to launch its own line of protein alternatives.

Other food industry actors have chosen the path of acquisition to enter the market for plant-based meat alternatives. Following Pinnacle Foods’ acquisition of Gardein for US$154 million in 2014 – to add the brand to the Birds Eye Frozen Division – Pinnacle’s CEO Bob Gamgort stated that “plant-based protein is at the tipping point of becoming mainstream, making Gardein an exciting new growth platform for the Birds Eye business.”

In 2017, Canada’s largest meat producer, Maple Leaf Foods, acquired Field Roast Grain Meat Co. for US$120 million. Other notable acquisitions include Monde Nissin’s purchase of Quorn for US$832.37 million in 2015, and Nestle’s purchase of Sweet Earth Foods for an undisclosed amount in 2017.

In late 2018, plant-based meat companies Impossible Foods and Beyond Meat were the joint recipients of the UN’s highest environmental honour, the Champion of the Earth Award. The novel technology and sustainability benefits of plant-based meats have attracted funding from high-profile tech investors and environmentalists including Leonardo DiCaprio and Twitter co-founders Biz Stone and Evan Williams. Impossible Foods is currently the top-funded start-up in the alternative protein space, raising nearly US$400 million from high-profile investors like Gates and Hong Kong business magnate Li Ka-Shing. Google Ventures, the investment arm of Google’s parent company, Alphabet, has also invested in Impossible Foods. Speaking at the 2016 Milken Institute Global Conference, Alphabet Executive Chairman Eric Schmidt named plant-based meat as the number one game-changing technology, surpassing 3D printing, autonomous cars, and other notable technologies.

In New Zealand, Sunfed Meats closed a NZD$10 million Series A fundraising round in November 2018, led by Australia’s Blackbird Ventures.” to fund the company’s next stage of growth and international expansion.
VARIED PLANT-BASED MEAT ALTERNATIVES

Plant-Based Meats

Plant-based meats consist wholly of plant-based ingredients, and aim to replicate the experience of cooking and eating conventional meat – from preparation methods to appearance, texture and flavour. To achieve this, food technologists develop unique combinations of plant proteins, fats, gums, spices and seasonings. Some of these ingredients are processed using extruders or unique processing technology that controls the moisture, heating, cooling and pressure to create functional, taste and textural properties.

Examples:

Beyond Meat began releasing pre-packaged ready-to-cook plant-based meats in 2016. The products contain no soy, genetically modified organisms or gluten.

Similar to Beyond Meat, Sunfed Meats uses Canadian yellow pea protein as its primary base, though it also incorporates ingredients sourced from New Zealand, including pumpkin and maize starch. Sunfed’s pre-packaged, frozen chicken alternative contains 62 percent more protein than a lean, skinless chicken breast and employs proprietary processing technology to mimic the texture of conventional chicken.

Impossible Foods debuted the Impossible Burger in 2016 with an update launched in 2019. The Impossible Burger uses a plant-based ‘heme’, found in the root nodules of soybean plants, which the company claims is responsible for the ‘bloody’ effect and unique meat aromas.

Funky Fields’ “Minced” was launched across Australia in 2018 through Woolworths supermarkets, selling out in hundreds of stores within the first week. Made in Denmark from soy, wheat, almonds and mushrooms, the product is stocked alongside conventional meat in Woolworths stores.
Nature’s Meat Mimics

Naturally occurring plant products including jackfruit and banana blossom can be prepared as meat alternatives due to their meat-like appearance, texture or ability to absorb flavours. These products appeal to consumers seeking minimally processed options that are similar to the experience of eating conventional meat.

Examples:

Banana blossom is comprised of tear-shaped flowers found at the end of a banana cluster. When battered and fried, the colour and texture bears a striking resemblance to fish. Due to increasing popularity for plant-based fish alternatives, Sutton and Sons from East London has developed a process to marinate the banana blossom in spices before mixing it with seaweed and frying it to create plant-based fish and chips.60

Together with Ocean Hugger Foods, leading American chef, Certified Master Chef James Corwell, created Ahimi, an alternative to raw tuna. Ahimi is made by combining roma tomatoes with ingredients such as sesame oil and sugar and subjecting it to a sous-vide cooking process to produce a flesh-like product that is firm and juicy, with a savoury bite.61 Ocean Hugger Foods is also developing eggplant eel called Unami and carrot-based salmon sashimi named Sakimi.62

Jackfruit has gained popularity as a substitute for pulled pork. When cooked it has a shredded and chewy texture.63 Jackfruit is now available in a wide variety of restaurant dishes and in packaged form by food suppliers such as Upton’s Natural and The Jackfruit Company,64,65 which are available at IGA stores in Australia.

Fermentation-Based Meat Alternatives

Proteins produced through fermentation can be derived from certain varieties of fungi. The typical production process for these meat alternatives involves the use of fermenters similar to those found in a brewery. Fungi are introduced to a nutrient solution, predominantly comprised of water and glucose, and given a continuous feed of nutrients — with pH balance, temperature, nutrient concentration and oxygen continuously controlled to promote optimum growth. The product is heated to remove excess ribonucleic acids, harvested, seasoned and mixed with a binding ingredient. This mix is then steam cooked, chilled and shaped into the final product prior to freezing to facilitate the consolidation of fibres to create a final meat-like texture.66

Examples:

UK company Quorn initially introduced their fungi-based meat alternatives in 1985, and now offers a range of pre-packaged meats and meals ranging from nuggets to lasagne.67 The company is on track to become a billion dollar business by 2027.68

Koji is a fungus that has been used for thousands of years in foods such as miso soup, soy sauce and in the production of sake. The start-up company Prime Roots, formerly known as Terramino Foods, is utilising it as a key ingredient to create burgers that offer a complete protein source, taste like salmon and offer a lower fat content.69
ENVIRONMENTAL IMPACT

Plant-based meat production requires significantly fewer natural resources than conventional meat and emits far less greenhouse gases. Utilising land to produce crops for human consumption instead of animal feed would reduce the overall environmental footprint of food production, preserve land and water resources, and represent an important step towards the goal of feeding a growing population within planetary boundaries.

Figure 4. Environmental impact comparisons with conventional beef. Figures based on U.S production systems.

<table>
<thead>
<tr>
<th></th>
<th>BEYOND MEAT™</th>
<th>IMPOSSIBLE™</th>
<th>HUNGRY PLANET™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>93% LESS LAND</td>
<td>95% LESS LAND</td>
<td>97% LESS LAND</td>
</tr>
<tr>
<td>Water use</td>
<td>99% LESS WATER</td>
<td>75% LESS WATER</td>
<td>90% LESS WATER</td>
</tr>
<tr>
<td>GHG Emissions</td>
<td>90% FEWER GHG EMISSIONS</td>
<td>87% FEWER GHG EMISSIONS</td>
<td>96% FEWER GHG EMISSIONS</td>
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</table>
Plant-based meats are generally moderate to high in protein content. The nine amino acids that are essential to the human body are now recognised to be readily available in certain plant-based foods, with common ingredients in plant-based meat – such as soy and quinoa – being rich in all nine.\(^73\)

Unlike conventional meat, plant-based meat alternatives contain no cholesterol, and can be produced with no trans fats. Levels of monounsaturated, polyunsaturated and saturated fats vary greatly across plant sources, with plant-based meats that contain coconut or palm oils being generally higher in saturated fat.\(^74\) Improvements can be made to plant-based meat alternatives to optimise the nutritional profile, taste and texture.

Some companies producing plant-based meat alternatives fortify their products with essential micronutrients. One such example is Australian-made Vegie Delights sausages, which provide 100 percent of the recommended daily intake of B12, 30 percent of iron and 35 percent of zinc per serving.\(^75\) Comparable nutrient levels are found in the Impossible Burger.\(^76\) Further, dietary fibre and phytonutrients are found only in plants, meaning plant-based meat products containing these nutrients can offer additional benefit over conventional meat products.\(^77\)

Some concerns about the processed nature of plant-based meats have been raised,\(^78,79\) including levels of sodium and saturated fats. However, comparisons with pre-seasoned conventional products are favourable.

### Figure 5. Nutritional comparison between plant-based meat alternatives and equivalent conventional meat product.\(^80\)

#### Burgers (per 100g)

<table>
<thead>
<tr>
<th></th>
<th>Conventional beef burgers*</th>
<th>Beyond Burger*</th>
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<tbody>
<tr>
<td>Energy (calories)</td>
<td>273</td>
<td>241</td>
</tr>
<tr>
<td>Protein (g)</td>
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<td>18</td>
</tr>
<tr>
<td>Fat (g)</td>
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<td>-of which saturated (g)</td>
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<td>4</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>4.2</td>
<td>4</td>
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<tr>
<td>Dietary Fibre (g)</td>
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<td>3</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>515.5</td>
<td>339</td>
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</table>

*Based on nutrition panel averages of Coles Beef Burgers, Woolworths Market Value Beef Burgers, and Beyond Burger (all pre-seasoned products).

#### Nuggets (per 100g)

<table>
<thead>
<tr>
<th></th>
<th>Conventional chicken nuggets*</th>
<th>Fry’s Meat Free (chicken-style) nuggets*</th>
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<tbody>
<tr>
<td>Energy (calories)</td>
<td>237.5</td>
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</tr>
<tr>
<td>Protein (g)</td>
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<td>10</td>
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<td>Fat (g)</td>
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<td>-of which saturated (g)</td>
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<td>Carbohydrate (g)</td>
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<tr>
<td>Dietary Fibre (g)</td>
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<tr>
<td>Sodium (mg)</td>
<td>545.5</td>
<td>669</td>
</tr>
</tbody>
</table>

*Based on nutrition panel averages of Coles Chicken Nuggets, Woolworths Essentials Chicken Nuggets and Fry’s Meat Free (chicken-style) nuggets.
There are thousands of plant proteins in the world, and many of them have yet to be explored for use in the production of meat alternatives. Current investigations of the world’s vast array of plant proteins could fundamentally reshape our food supply for the better.”

— Bill Gates

Processing Technology

Despite significant product innovation in the category of plant-based meat alternatives, processing innovation remains limited and would benefit from significant efficiency and quality-control improvements. Many plant-based meat alternatives are produced via extruders – machines that apply heat and mechanical shear stress to coax plant proteins into desired textures such as aligned fibers. Though extruders have proved valuable in the production of plant-based meat alternatives, they were initially designed for – and are still used to produce – various non-food products, as well as dried foodstuffs such as breakfast cereals and pasta. Very few design improvements have been made to optimise extruders for the purpose of plant-based meat production, which has unique requirements. Other lower-tech methods of production, like mixing and press-forming, simply require optimisation and automation for greater throughput.

Couette Cell (also known as shear-cell) technology, researched as part of a public-private partnership in the Netherlands, is among the most novel approaches to the production of plant-based meat alternatives. Using a shearing approach, as opposed to the application of heat and pressure, the Couette Cell is more energy efficient and results in a plant-based meat alternative with a steak-like texture.

Protein Discovery and Characterisation

The vast majority of plant proteins have not yet been examined for their potential use in plant-based meat alternatives, and it is impossible to quantify the potential applications of plants that are not commonly used in today’s food supply. Alternative protein company JUST (formerly known as Hampton Creek), has stated that it is using its robotics platform to screen thousands of plant species for protein characterisation, and has promised to share this information in the form of a public database at a later date. However, the timeline and relative success of this project remains unclear. Given the sizeable potential benefits of new protein discovery, additional research efforts are needed.

The rise of plant-based meat alternatives presents opportunities for conventional agriculture through increased demand for more specialised crops, for example, Canadian yellow pea protein, which is used by both Beyond Meat and Sunfed. Good Catch’s fish-free tuna incorporates six types of plant proteins to achieve a tuna-like texture and high nutrient content. These examples illustrate a critical benefit of plant-based meat alternatives: innovation in this sector supports the creation of new value throughout the supply chain and could encourage crop diversity, soil health preservation, and promote new business opportunities for farmers.
Plant-Based Meat Alternatives as Ingredients

Significant opportunity exists in marketing plant-based meat alternatives as ingredients, as opposed to creating branded, standalone products. Such partnerships are increasing in popularity in the plant-based sector, where soy and nut-based cheese companies are selling products to brands that specialise in pre-packaged pizzas and pasta dishes.

Given the rise in popularity of convenience options, companies producing plant-based meat alternatives could find significant additional revenue streams by supplying buyers in the frozen-food and institutional foodservice markets. One company taking this approach is Hungry Planet, whose range of plant-based burgers, chicken and sausage is used in restaurants such as Mesa Burger, and is available to chefs in bulk commercial quantities.

Regulatory Status

Many major players in the conventional meat industry are seeking to capitalise on the trend toward plant-based protein consumption. Tyson Foods, for example, has re-positioned itself as a protein company, rather than a meat company – a subtle shift that marks a big change in approach.

While some businesses see opportunity, other industry incumbents view the emergence of plant-based meats as a competitive threat, and are actively seeking regulation in favour of the status quo. Some countries have seen efforts to ban the use of the term ‘meat’ and related sub-categories in the labeling and marketing of plant-based meat alternatives. While it’s unclear what effect this will have on consumers’ willingness and ability to purchase these products, this early push-back could foreshadow stronger resistance led by some conventional meat industry groups.
CELL-BASED MEAT

BACKGROUND

Advances in cell-culturing technology have made it possible to grow meat directly from cells, obviating the need to breed, feed and kill animals. This emerging field is known as cellular agriculture. Cell-based meat, also referred to as ‘clean meat’ due to its environmental and food safety benefits, has emerged as a potential solution to meet the world’s growing protein demands.

Cell-based meat involves taking a small sample of animal cells and housing them in a bioreactor – also known as a cultivator – where the sample is fed a mixture of nutrients and signaling proteins, causing cells to grow and divide. The process mimics that of growing flesh on an animal, but removes the need for a live animal to produce the desired end-product.

In 2005, NASA conducted initial investigations into the feasibility of cell-based meat as a way to feed astronauts on long-haul spaceflights, providing funding to culture turkey muscle cells in vitro. Researchers immediately saw the technology’s potential to alleviate food supply and safety issues on Earth.

While this technology has only recently become a reality and is still not commercialised, its rapid development has caught the eyes of governments, business and environmentalists around the world.
In 2013, Professor Mark Post of Maastricht University captured the public’s interest at a London press conference, where he unveiled the world’s first beef burger created without killing cattle.\(^3\)

Taking his project out of academia, Post launched Mosa Meats, courted millions in funding and reduced production costs considerably from an estimated A$400,000 prototype to an anticipated A$15 once at industrial scale, with plans to reduce costs further to the price of conventional supermarket burgers in the next decade.\(^1\)

As the prospect of cell-based meat moves from hypothetical to commercially viable, Mosa Meats has been joined by more than 20 cell-based meat companies globally, including Memphis Meats in the U.S., SuperMeat in Israel, Higher Steaks in the UK, Shiok Meats in Singapore and Meatable in the Netherlands. Meanwhile, other companies are using cell-culturing technology to produce different animal products, from egg whites (Clara Foods), to dairy (Perfect Day) to gelatin (Geltor).

Several companies have developed prototypes of cell-based meat since Post’s burger. Memphis Meats has produced prototypes of meatballs and poultry products,\(^5\) Finless Foods has prototyped cell-based tuna croquettes,\(^6\) and New Age Meats launched cell-based pork sausage prototypes to journalists and potential investors in September 2018.\(^7\) JUST has also given journalists samples of its cell-based chicken nugget prototype.\(^8\)

Examples:

- Memphis Meats
- New Age Meats
- SuperMeat
- Mosa Meat
- Meatable
- Shiok Meats
- Finless Foods
- Higher Steaks
- JUST
With technological advancements and production efficiency gains, the cost of producing cell-based meat has continued to fall, with some predictions of a high-end product being available on the market as early as 2020. Some cell-based meat companies aim to be cost competitive with conventional meat in supermarkets within five to 10 years.

**Figure 6. Declining production costs for cell-based meat.**

<table>
<thead>
<tr>
<th>Date</th>
<th>Product</th>
<th>Company (Location)</th>
<th>Cost (AUD) per kilogram unless otherwise stated</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>Beef Patty</td>
<td>Mosa Meats (Netherlands)</td>
<td>$3.2M</td>
</tr>
<tr>
<td>March, 2017</td>
<td>Southern Fried Chicken</td>
<td>Memphis Meats (USA)</td>
<td>$27,000</td>
</tr>
<tr>
<td>March, 2017</td>
<td>Duck à l’orange</td>
<td>Memphis Meats (USA)</td>
<td>$27,000</td>
</tr>
<tr>
<td>Mid-2018</td>
<td>Minced Meat</td>
<td>Memphis Meats (USA)</td>
<td>$6,000</td>
</tr>
<tr>
<td>May 2018</td>
<td>Minced Meat</td>
<td>Future Meat Technologies (Israel)</td>
<td>$1,122</td>
</tr>
<tr>
<td>October 2018</td>
<td>Pork Sausage</td>
<td>New Age Meats (USA)</td>
<td>$303/sausage</td>
</tr>
</tbody>
</table>

**Future predictions:**

<table>
<thead>
<tr>
<th>Date</th>
<th>Product</th>
<th>Company (Location)</th>
<th>Cost (AUD) per kilogram unless otherwise stated</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>Minced Meat</td>
<td>Future Meat Technologies (Israel)</td>
<td>$7.14</td>
</tr>
<tr>
<td>Prediction – near future</td>
<td>Minced Meat</td>
<td>JUST (USA)</td>
<td>Within 30% of price of conventional meat</td>
</tr>
<tr>
<td>Prediction – when scaled to industrial size</td>
<td>Beef Patty</td>
<td>Mosa Meats (Netherlands)</td>
<td>$14.24/burger</td>
</tr>
<tr>
<td>Prediction – unspecified</td>
<td>Pork Sausage</td>
<td>New Age Meats (USA)</td>
<td>$7/sausage</td>
</tr>
<tr>
<td>Prediction – next decade</td>
<td>Beef Patty</td>
<td>Mosa Meats (Netherlands)</td>
<td>$1.60/patty</td>
</tr>
</tbody>
</table>
Like their plant-based counterparts, cell-based meat companies have rapidly attracted attention from major investors including conventional meat corporations, high-profile investors such as Richard Branson, and tech moguls including Google co-founder Sergey Brin – who funded the very first cell-based burger.22

Memphis Meats, one of the best-known start-ups in the sector, has received US$20 million in total funding from Cargill and Tyson Foods, DFJ, Bill Gates, Kimbal Musk, and others.23 JUST, which began as a plant-protein company and which has raised more than US$220 million from an investor pool including Khosla Ventures, Eduardo Saverin (Facebook co-founder), Marc Benioff (Salesforce founder), and Hong Kong business magnate Li-Ka-shing, announced its expansion into cell-based meat in 2017.24

Conventional meat companies, observing the confluence of technology and consumer sentiment, have been incentivised to participate in the transformation of the protein industry, rather than risk being disrupted by outside competition. PHW-Gruppe, one of Europe’s largest poultry producers, invested in Israeli cell-based meat start-up SuperMeat and made it clear that they intended to partner with SuperMeat on research, development and strategic product positioning.25 Multinational life science industry leaders such as Merck KGaA, through its investment in Mosa Meats, are also demonstrating interest.26 Given the nascent stage of the industry, investment in cell-based meat is a high-risk, high-reward proposition.

Governments are also buying in. Singapore – with its confined geography, heavy reliance on food imports and focus on food security – has pledged nearly US$14 billion for research and development.27 In February 2019, the Maharashtra government in Western India announced it was establishing a centre for excellence in cellular agriculture, set to be the “world’s first dedicated centre on cellular agriculture” in order to promote research, development and production of cell-based meat.28

Figure 7. Capital raised by dedicated cellular agriculture companies (USD).

- Modern Meadow: $53.5M
- Perfect Day: $40M
- Geltor: $23M
- Memphis Meats: $20M
- Mosa Meats: $8.8M
- Finless Foods: $6.7M
- Meatable: $3.5M
- Clara Foods: $3.5M
- Future Meat Technology: $2.2M
- New Age Meats: $0.25M

Source: Crunchbase.com

If we can grow the meat without the animal, why wouldn’t we?”

— Tom Hayes, Former CEO, Tyson Foods
Meat Re-Imagined

Producing cell-based meat requires four critical technologies: cell lines, culture medium (also called nutrient medium or feed), scaffolding and bioreactors (also called cultivators). These components are at various degrees of development, and none are yet fully optimised for industrial-scale production of cell-based meat.

**Figure 8. Cell-based meat production process.**

### Cell Line Derivation
A small sample of cells is obtained from an animal.

### Phase 1: Cell Proliferation
The cells are added to a bioreactor along with cell culture media, which causes the cells to proliferate.

### Phase 2: Tissue Perfusion
A change in culture conditions pushes the cells to differentiate into muscle, fat, and connective tissue.

### Cell Starter Culture

### Cells at Maturation
Primarily muscle, fat, and connective tissue.

### Fat Cell

### Muscle Cell

### Fibroblast Cell

### Scaffolding

### Final Product

Source: The Good Food Institute.

### Cell Lines
Cell lines provide the species-specific starter material for cell-based meat. While cells can be isolated from samples from animals in an essentially painless procedure, the proliferative potential of most adult-derived cells is small; they can typically only divide about 20 to 50 times, depending on the cell type. While these adult cells may be suitable for some products and processes, many companies are developing immortalised cell lines that can proliferate indefinitely. Immortalisation can be achieved through genetic modification; however, some pluripotent and multipotent stem cells – cells that can grow and differentiate into all of the cell types required for meat – already exhibit this capacity. Developing, maintaining, and storing these cell lines may become a vertically integrated aspect of cell-based meat production, or it could be outsourced to third-party partners.

### Culture Medium
The cell culture medium contains the nutrients that the cells metabolise to support their growth (including amino acids, sugars and vitamins), as well as components that maintain a stable osmolarity and pH. It also contains a suite of signaling proteins called growth factors that provide instructions to guide the cells. For example, to encourage proliferation or to trigger differentiation down pathways to mature into the desired final cell types (muscle, fat, connective tissue, etc.). The cost of most cell culture media is currently very high as animal cell culture has traditionally been used for high-cost applications like biomedical research, cell therapies and biopharmaceutical therapeutics. Thus, it has not been subjected to the cost constraints of the food industry, nor has it been specifically optimised to support the growth of the cell types and species that are relevant for cell-based meat.
Growth factors are currently the major cost drivers of cell-based meat, and present the greatest opportunity for cost reduction. Historically, growth factors have been most easily obtained through fetal bovine serum (FBS), which is a byproduct of meat processing. FBS has batch consistency problems, is the main contributor to the costliness of growth media, and is in short supply. Ethical issues also arise through the extraction method for those working to create cell-based meat production, where the aim is to remove animals from the process entirely. Cell-based meat companies have stated their commitment to replacing this input with an animal-origin-free alternative. Future Meat Technologies, based in Israel, uses a serum-free process that cleans and recycles their media, which is important as it constitutes their largest expense. Mosa Meats, who say media comprises 80 percent of production cost, have developed a working serum-free medium, but indicate that it still requires optimisation. Israeli start-up Aleph Farms has also developed an animal-friendly alternative to FBS. Meatable, a relatively new Dutch start-up, has developed a bovine pluripotent stem cell line that does not require FBS and will proliferate indefinitely.

Animal-origin-free media are available in the biomedical industry, but they are currently cost-prohibitive in the context of food production. Despite this fact, cross-industry collaboration is already ameliorating concerns that affordable, meat-optimised growth media will pose obstacles, with projections suggesting that growth media could be made significantly less expensive through scaled production and research into cost-effective growth factors. One of the few analyses of media that focuses specifically on cell-based meat production concluded that, despite the engineering and biological challenges involved in reducing the cost of media and removing animal components, none of these challenges will require wholly novel inventions or ‘moonshot’ technological breakthroughs. As the primary input of cell-based meat, successfully reducing the cost of growth media will be essential for economic viability.

### Scaffolding

Scaffolding is a physical support structure that allows cells to adhere to it as they differentiate into the necessary cell types and spatial arrangement to create the familiar look and texture of popular cuts of meat.

There are two primary approaches to creating cell-based meat scaffolds. The first is to use an edible, food-grade, taste-neutral material that can be consumed along with the final product. Research is presently underway to refine existing examples such as alginate, an algal derived polysaccharide currently used as a gum in the food industry, and develop new materials. The second is to use biodegradable materials that the cells will break down as they grow and create their own self-made scaffold called the extracellular matrix.

While scaffolding is important for replicating cuts of meat that require high textural variation such as a marbled steak, complex scaffolding is not necessarily required for all cell-based meat products. Many popular conventional meat products get their texture from downstream processing, such as the formation of chicken patties, minced beef or sausages. As long as the necessary muscle, fat and connective tissue are present in sufficient quantities, these products can be created without significant scaffolding innovation.

### Bioreactors

Bioreactors, which are commonly referred to as ‘cultivators’ within the industry, are the proverbial barns for cell-based meat production. Bioreactors are the closed systems wherein the cells are maintained at optimal conditions to support high-efficiency proliferation and differentiation. While a variety of bioreactors have been designed to mimic the natural growth environment for various cell types, including a scalable modular bioreactor prototype funded by New Harvest, none have yet been optimised for mass cell-based meat production.

At scale, novel problems may arise, such as oxygenation and recycling of growth media. Additionally, engineers must develop a method for continuous – as opposed to batch – processing to ensure maximum time and cost efficiency.

Scaling up production from working models of tissue-growth in the biomedical industry to low-cost commercial food production in bioreactors remains a hurdle to large-scale cell-based meat production, however advances are being made. Notable advances include the development of a method to cultivate cells on beads in suspension within bioreactors called microcarriers. Meatable claims to have made progress developing technology to overcome scalability issues – including establishing cells that do not require surface attachment in the initial proliferative stage – and is working on the development of an animal-free edible or biodegradable scaffolding material. Meanwhile, Israel-based Aleph Farms has developed a three-dimensional process incorporating the four elements of meat (muscle, fat, connective tissue and blood vessels).
Environmental Impact

At scale, cell-based meat is projected to require significantly less land and water than feeding and raising cattle. Initial lifecycle analyses have shown that cell-based meat could require as little as 1 percent of the land that meat production requires today.\(^47\)

The results of a recent study from the University of Oxford,\(^48\) modelling potential climatic impacts of cell-based meat versus conventional beef cattle systems, were released in February 2019. This study highlighted the difficulties in making such predictions in the absence of accurate life cycle assessments for scaled up cell-based meat production, as well as the importance of utilising decarbonised energy sources to power facilities and transportation. However, even without an almost inevitable transition to renewable energy, and assuming no new efficiencies with scaling up of cell-based meat, the benefits across all models in the study were strongly in favour of cell-based meat for the first 100 years.\(^49\)

While creating the same, or potentially improved, sources of protein with markedly fewer resources, cell-based meat frees up some non-rangeland arable land to grow crops for human consumption, as opposed to growing crops for animal feed. This has the potential to compound the positive impacts on food system productivity and food security.

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**Figure 9.** Environmental impact comparisons with conventional beef. Figures based on European production systems.

<table>
<thead>
<tr>
<th>Study 1: Tuomisto &amp; Mattos 2011(^40)</th>
<th>Study 2: Tuomisto &amp; Roy 2012(^41)</th>
<th>Study 3: Tuomisto, Ellis &amp; Haastrup 2014(^42)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land use</strong></td>
<td><strong>Land use</strong></td>
<td><strong>Land use</strong></td>
</tr>
<tr>
<td>99% LESS LAND</td>
<td>99.7% LESS LAND</td>
<td>94% LESS LAND</td>
</tr>
<tr>
<td><strong>Water use</strong></td>
<td><strong>Water use</strong></td>
<td><strong>Water use</strong></td>
</tr>
<tr>
<td>82–96% LESS WATER</td>
<td>94% LESS WATER</td>
<td>48% LESS WATER</td>
</tr>
<tr>
<td><strong>GHG Emissions (CO(_2) eq/KG)</strong></td>
<td><strong>GHG Emissions (CO(_2) eq/KG)</strong></td>
<td><strong>GHG Emissions (CO(_2) eq/KG)</strong></td>
</tr>
<tr>
<td>78–96% LESS EMISSIONS</td>
<td>98.8% LESS EMISSIONS</td>
<td>95% LESS EMISSIONS</td>
</tr>
</tbody>
</table>
Cell-based meat, essentially the same as conventional meat at the cellular level, provides an opportunity to produce a protein with identical levels of amino acids and micronutrients as conventional meat.

There is potential to tailor the fat profile and quantity of cell-based meats or to enrich it with essential micronutrients such as vitamin B12—provided these are supplied in the growth medium. Professor Mark Post of Mosa Meats claims the company can produce cell-based meat containing omega-3 fatty acids and other healthy fats. While the nutritional profile of cell-based meat could be enhanced, it is identical to conventional meat on a cellular level, meaning that it will likely present similar health implications to those posed by conventional meat.

Through the environmental and hygiene control of production facilities, cell-based meat will be free of many issues that plague conventional animal agriculture, including bacterial contamination and widespread antibiotic use. Cell-based meat does not require the antibiotics used in some forms of livestock farming, similarly obviating the need for abattoirs, and avoiding the potential for contamination from faecal matter, E.coli, Salmonella enterica, Campylobacter spp. and other common contaminants in conventional meat.

Animals have biological limits, and manipulating these limits is a source of constant interest and risk within the conventional meat industry.

Despite selective breeding and genetic modification to produce fast-growing animals, and the use of antibiotics to keep animals alive in highly confined conditions, there are limitations to the volume of meat an animal can produce and the number of animals that can be fed and raised on a given tract of land. As global demand for meat increases, conventional animal agriculture is hitting the limits of its productive feasibility.

Cell-based meat is a tech-driven response to the risks of conventional animal agriculture that, if scaled successfully, could address a number of the negative consequences of conventional meat production.

Processing Technology

Significant hurdles remain to scaling production and achieving price parity with conventional meat. Many of the technologies crucial to cell-based meat production are not yet optimised for commercial scale and require engineering advances to enable competition with conventional meat and its current production methods. It should be acknowledged that while notable advances have been made in recent years, the cell-based meat industry has yet to benefit from the significant government-funded research and development seen in earlier emerging sectors, such as biopharmaceuticals, green chemistry and biotechnology. The nascent stage of cell-based meat technology leaves significant opportunity for further advancement and capitalisation as the sector matures.

Regulatory Status

The question of cell-based meat regulation has drawn significant interest in the United States, where discussions concerning primary oversight and nomenclature are ongoing. It is currently envisaged that responsibility for regulation will be jointly shared between the Food and Drug Administration and the United States Department of Agriculture, though the specifics of how this arrangement will work in practise are still unclear. The question of oversight is linked to a deeper regulatory complication, as meat regulation today is predicated on animal slaughter. As such, pre-existing pathways may prove insufficient to regulate cell-based meat before it enters the consumer market.

The U.S. government has given strong signals that they wish to streamline the regulation of cell-based meat in order to
become market leaders. The U.S. Secretary of Agriculture told the Wall Street Journal in November 2018; “we don’t want this new technology to feel like they’ve got to go offshore or outside the United States to get a fair regulatory protocol.” The meat industry, on the other hand, is split. Some major producers – including Tyson Foods and Cargill – have invested in cell-based meat companies, while other industry groups such as the National Cattlemen’s Beef Association (NCBA) are lobbying to bar cell-based meat companies from labeling their products as meat. The split is occurring primarily between the poultry and pork industries – which are highly vertically integrated and tend to embrace technology-driven efficiency advances – and the cattle industry – which is less consolidated and more defensive of its independent operators.

Closer to home, the Agri-Food & Veterinary Authority of Singapore (AVA) has engaged with the cell-based meat industry since its early days, reflecting a high level of interest in fast-tracking regulatory pathways.

Consumer Perceptions

Even with adequate funding for scale-up and a favourable regulatory environment, consumer education may be required in advance of market entry for cell-based meat to be widely accepted. While cell-based meat has the potential to deliver significant benefits relating to sustainability and food safety, and has the potential for improved nutrition and taste, it’s unclear whether consumers will embrace the products. Perceptions of unnaturalness and fear of unfamiliar foods could compromise adoption.

Surveys of consumers show mixed interest, and vary greatly depending on the descriptors used and information provided. A Pew Research study of approximately 1000 U.S. adults found that 20 percent of respondents would “eat meat that was grown in a lab” – a considerable number given the lack of context. A 2013 poll in the Netherlands explained that cell-based meat would have the same flavour, texture and nutritional value as conventionally produced meat, and 70 percent of the poll’s 1000 respondents said that they would try it.

A joint poll by Faunalytics and U.S.-based non-profit organisation The Good Food Institute (GFI) tested different positive messaging for cell-based meat, as well as negative messaging related to conventional meat. When given information about the use of antibiotics in conventional animal agriculture and the unnatural rate of growth for modern farm animals, nearly half of respondents reported that they would try cell-based meat and be willing to pay a premium for it. In addition, a 2013 Belgian poll of 180 adults found that only 9 percent rejected the idea of trying cell-based meat, with evidence of significant gains in acceptance following the provision of educational materials on the environmental benefits of cell-based meat over conventional meat production. In 2019, GFI will partner with research firm Mattson to conduct research on nomenclature and messaging for optimal consumer perception.

Egg, dairy, gelatine

Alongside cell-based meat, some companies are developing other animal-derived proteins including acellular alternatives to conventional dairy, eggs, and gelatine.

Acellular production focuses on creating animal proteins through a non-animal product host, rather than by growing animal cells. The process is akin to that of fermenting beer. Similar to yeast in brewing tanks which feed on sugars to produce alcohol, microbes (including yeast) can be used to produce proteins. These proteins can, in turn, be used to create products much closer to a conventional equivalent than to a wholly plant-based product.

While acellular production appears novel, it is already used to produce food products such as rennet, a common ingredient in cheesemaking, as well as medical products like insulin. Additionally, it can be used to optimise animal proteins in a way that cannot be done through conventional methods, such as increasing the binding and emulsification abilities of egg proteins or removing lactose from dairy products. Several companies are utilising acellular protein production in prototype and proof-of-concept stages, including Clara Foods’ non-animal egg-whites and egg proteins for other functional uses. Perfect Day has created cell-based dairy products, and Geltor has created non-animal collagen that can be used in food, medicine and cosmetics. Perhaps most notably, plant-based meat company Impossible Foods is using an acellular process to produce the iron-containing molecule heme, found within the plant-based leghemoglobin protein, giving its burgers a ‘bloody’ appearance and flavour.

In 2018, Singaporean state-owned investment firm Temasek led a US$24.7 million series A funding round in cell-based dairy company, Perfect Day, followed by an additional US$34.8 million series B funding in February 2019, demonstrating confidence in the ability of the company to scale and commercialise.
HYBRIDS

Hybrid meat products occupy a middle ground between conventional meat and their alternative counterparts, enabling a reduction of conventional meat consumption without a significant shift in consumer behaviour. While the conventional meat industry already makes use of fillers and extenders, technological advances in plant-based meat, cell-based meat, and insect protein production offer new ingredients to add flavour, texture, and protein to familiar dishes.

PLANT-BASED BLENDS

Hybrid meats that incorporate mushrooms and other plant-based ingredients are already familiar to consumers, and are relatively simple to produce at both home and at commercial scale. Advances in plant protein characterisation and processing technology are making it possible to increase the ratio of blending ingredients to conventional meat in popular foods without compromising taste and texture. As a result, an increasing number of companies are offering these products in both retail and restaurant environments. As consumer demand and industrial production increase, the cost of plant-based hybrids is anticipated to decrease relative to conventional meat.

Examples:

Australian company Perfectly Balanced sells blended products including meatballs with kale and sweet potato, sausages with carrots and herbs and burgers with semi-dried tomato and basil, at Woolworths. While these blends do not represent a significant technological advancement in terms of protein characterisation or optimisation, they appeal to a growing number of health-conscious and sustainability-minded consumers.

U.S.-based Better Meat Co is a business-to-business supplier of plant protein blends to institutional food service providers and meat processors. The company’s blends are designed to be incorporated into products like meatballs, sausages, fish sticks, chicken nuggets, burgers or other ground meats, and are the result of significant R&D efforts to match flavour and texture profiles of these specific meat products.
**CELL-BASED BLENDS**

Given the significant cost of producing cell-based meat today, it is possible that the earliest commercially available products will be blended with plant proteins.

Such products would not only significantly reduce costs compared to fully cell-based products, but may additionally serve as an introductory format to gauge consumer acceptance and increase consumer education.

*Examples:*

U.S.-based researcher Marie Gibbons produced a cell-based turkey nugget blended with jackfruit at North Carolina State University. The jackfruit not only added texture to the final product, it was also used as scaffolding for cell proliferation during development.  

Spanish start-up Cubiq Foods is developing animal fats through cell-culturing techniques. It is anticipated that these products will eventually be incorporated into plant-based meat alternatives to provide specific flavour and functional benefits of animal fats that are difficult to replicate with plant sources.  

**INSECT-BASED BLENDS**

Insect-based ingredients are primarily used in products like muffins, pasta and nutrition bars, although a small number of companies are beginning to incorporate them with conventional meat or plants, to present the insect component in a more familiar format.

While there are few examples of insect-meat blends, researchers are currently investigating approaches to develop such products. With Western consumers generally reluctant to eat insects due to food and cultural norms, manufacturers are increasingly focusing on producing protein-rich insect flours and powders instead of offering whole insects. Investment in insects as meat alternatives has been limited due to functionality limitations, scale-up challenges and low consumer acceptance.

*Examples:*

Swiss start-up Essento incorporates a variety of grains, pulses and vegetables into its mealworm-based ‘meatballs’ and burgers, sold at the country’s second-largest supermarket chain, Coop.

Edible Bug Shop, based in Sydney, focuses on crickets, mealworms and ants for human consumption. The company is exploring methods of incorporating insects into conventional meat products.
PROSPECTS FOR AUSTRALIA

The emerging alternative proteins sector presents a significant opportunity to diversify global food production. Markets in Europe, Israel, the U.S. and Asia are vying for supremacy, however, Australia has a window of opportunity to become a first-mover, harness its expertise and infrastructure, and become highly competitive as the industry scales up.

CONSUMERS

Millions of Australians are seeking out more plant-based foods. Australia is one of the fastest growing markets in the world for plant-based products, with a projected compound annual growth rate of 9.6 percent. To meet this demand, an increasing number of plant-based products – from plant-based meat alternatives to plant-based milks – are becoming widely available to consumers in supermarkets, restaurants and cafes.

A considerable number of the plant-based meat alternatives currently available in the Australian market are imported. A significant opportunity exists to satisfy this demand with locally produced products, made with Australian-grown ingredients. More Australian investment in product innovation will incentivise businesses to cater to this growing demand, and offer consumers a greater variety of protein options that satisfy their hunger for healthier, more sustainable foods in familiar forms.

Items that were once relegated to the far-corners of grocery stores, and reserved for those with allergies or dietary restrictions, are rapidly increasing in popularity and market share. The rising consumer demand for plant-based milks in the U.S. provides an instructive case study. Demand in the U.S. has propelled plant-based milks to 13 percent of sales in the fluid milk and dairy alternatives market, with plant-based milks catering to an increasingly broad cross section of consumers interested in differentiated products, utility and nutritional qualities.
Australia offers a wealth of advantages to international alternative protein businesses and local start-ups seeking to establish an Asia Pacific base of operations. Australia’s secure, stable regulatory environment, good governance, strong intellectual property laws, access to finance and support for small businesses provides an ideal platform for new enterprise.

Australia is a globally integrated economy in its 27th year of uninterrupted economic growth, with deep links into dynamic Asian economies through established supply chains, including the largest economies in the world such as Japan and China, Australia’s largest two-way trading partner. Australia’s food manufacturing sector includes well over 5,000 registered food and processing manufacturing facilities, mostly concentrated in the eastern states of Victoria, Queensland and New South Wales. A recent Australian Government report found that Australian manufacturers and processors have particular experience producing specialty processed foods that meet flavour (e.g. European and Asian tastes), convenience (e.g. ready-to-serve), nutritional benefits (e.g. salt/fat/sugar reduced) and functionality (e.g. probiotics) requirements. These same requirements have been an area of focus for R&D of plant-based and cell-based meats, meaning Australia is well placed to develop and manufacture such products.

The potential national economic benefits of embracing protein innovation are far-reaching, including job creation through manufacturing and distribution to research and marketing. Critically, these benefits are not limited to new market entrants, but present collaborative growth opportunities with established industries, particularly in the grain, pulse, manufacturing and life sciences sectors.

Alternative protein businesses can leverage Australia’s strong development, manufacturing and export base, including partnering with existing conventional meat exporters through new cooperative ventures to become a leader in the regional alternative protein market. This enables international alternative protein businesses to establish Australian manufacturing facilities to access Asian markets, as well as provide an avenue for Australian start-ups to access existing supply chains. In addition, as an advanced and sophisticated consumer market with high food standards, a high degree of ethnic diversity and a demonstrated consumer willingness to embrace novel products, Australia offers an ideal location for international alternative protein companies seeking to test new products in overseas markets.

With regional economies such as China increasingly focusing on alternative proteins, the opportunity for international cooperation, co-development of technology and the creation of new trade partnerships arises.

Internationally, fresh competition is driving an uptick of in-house innovation in alternative protein products. Blue-chip international brand Kraft Heinz launched Springboard, an incubator and accelerator program to identify disruptive food start-ups, including start-ups focused on developing plant-based proteins. To keep pace with their international counterparts, Australian food and biotech companies should invest in alternative protein development and the infrastructure that facilitates their availability and supply.

In neighbouring New Zealand, The Craft Meat Co., owned by conventional meat company Fisher Meat, launched a plant-based mince which was praised by the CEO of Beef+Lamb NZ as a show of initiative.

"Someone in the industry is showing initiative ... so I take my hat off to them. I don’t care that it’s not traditional mince at all, and I don’t think they do either as a meat company.”

— ROD SLATER, CHIEF EXECUTIVE, BEEF+LAMB NZ
**Science & Technology**

Australia is a world leader in research and development (R&D), with an annual expenditure of A$31 billion, or 1.9 percent of GDP. It ranks fifth globally for biotechnology innovation, despite having only 0.3 percent of the world’s population. Business expenditure on R&D reached A$16.7 billion in 2015-16, with Australian businesses investing over A$200 million a year in agribusiness R&D, and over A$700 million in food manufacturing R&D. The government provides A$800 million in funding to its own innovation research centre, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), which contributes R&D for practical industry implementation, such as new processing technology. The 2018 Budget also committed A$1.9 billion to invest in research infrastructure to support continued STEM innovation.

Additionally, Australia boasts 43 accredited universities, with seven in the top 100 globally. These institutions are known for their exceptional work in tech and R&D, partnering with government and the private sector to develop new innovations. For example, the development of a natural food preservative from native Kakadu Plum extracts that extends product shelf life by up to 18 months.

**Agriculture**

With global food demand expected to soar in the coming decades, alternative proteins represent a complementary upstream value add to Australia’s current A$58 billion agriculture sector. Plant-based meats produced in Australia with Australian-grown inputs provide a new market for Australian farmers, generating additional value in an agricultural supply chain already supporting 1.6 million Australian jobs.

Agricultural businesses occupy 51 percent of Australia’s landmass, with agriculture utilising 393 million hectares of land, of which 87 percent is used for grazing. Crop production is a A$33.6 billion industry, accounting for 54.5 percent of Australia’s total value of agricultural output, with crops including grains, nuts, fruits, vegetables and legumes offering a reliable supply of primary inputs.

Current plant-based meat products are largely comprised of protein from pulses and grains, presenting a new supply opportunity for farmers. Australia grows over 2 million tonnes of pulses, averaging just under 10 percent of the country’s crop area. Chickpeas total 31.7 percent, followed by lupins, field peas and others including faba beans, lentils, mung beans and navy beans. Australia also produces 50 million tonnes of coarse grain, rice and wheat crops annually, with wheat accounting for 64 percent, followed by barley, oats, sorghum and others. Vegetables totalled 3.5 million tonnes, worth A$4.29 billion for the year ending June 2017. All commercially grown crops are non-genetically modified, and certified organic varieties are available. Strict pest and disease controls, and a wide climatic range ensures that a reliable source of fresh, quality products are accessible year-round.

Growing greater volumes of nitrogen-fixing crops such as pulses has the dual benefit of supporting the long-term health and productive capacity of Australia’s soil and water resources, as well as the profitability and stability of its rural economy. Alternative proteins can form part of the new narrative of Australian food production, providing opportunities for farmers through demand for new crop varieties and primary inputs, and opportunities for rural communities across the supply chain.

Australia has at least 17 research institutions that produce work directly relevant to R&D for plant-based meat alternatives, including in the fields of stem cell research and regenerative medicine, tissue engineering, bioprocess engineering, and food science and product development. Australia also boasts one of the largest regenerative medicine research facilities in the world, the Australian Regenerative Medicine Institute at Monash University in Melbourne.

Australia is home to at least 32 research centres that produce work directly relevant to R&D for plant-based meat alternatives, including in plant genetics and molecular biology, crop science and production, and food science and product development. Australia also houses 15 Rural Research and Development Corporations (RDCs) – government supported bodies that fund research for rural industries. These partnerships provided A$750 million for agricultural R&D in 2017-18.

Australia’s wealth of relevant research capabilities offers a conducive environment for businesses to pursue original R&D in alternative proteins.
Prospects For Australia

Policy & Regulation

Government funding

With the decline of major economic sectors such as mining and automotive manufacturing, the Australian Government has focused on rebalancing the economy, investing in technology and innovation-led sectors, and galvanising long-standing pillars of the Australian economy such as agriculture.

The Australian Government could encourage local innovation in alternative protein R&D and production by allocating greater tax and funding incentives to these fields. This would entice local and international innovators to leverage Australia’s expertise and infrastructure to pursue their business efforts in-country.

Nomenclature

It is crucial that Australia’s labelling regulations support consumers to understand new alternative protein products, and to navigate supermarket shelves with ease.

Producers of plant-based meat alternatives generally use common, familiar terms, such as ‘sausages’, together with qualifiers such as ‘plant-based’, so consumers can easily understand the utility of new products while making their plant-based composition clear. Some industry incumbents, are advocating to ban or restrict terminology traditionally used to describe conventional meat and conventional dairy products, citing concerns about consumer confusion between conventional animal products and their plant-based counterparts. Regulators must consider whether restricting well-understood terms in Australia could have unintended consequences, such as manufacturers being forced to concoct unknown, contrived terminology that consumers might struggle to interpret.

Restrictive labelling may have the additional unintended consequence of deterring international plant-based meat manufacturers from establishing production and export operations in Australia. Restricting the product terminology these brands already successfully use across the world would only serve to diminish Australia’s natural competitive advantages over other markets.

Cell-based meat regulation

Australia’s labelling debate reflects a broader need for proactive regulatory policy as it relates to cell-based meat. With leading international meat companies such as Cargill and Tyson Foods investing in cell-based meat technology, the question is when – not if – cell-based meat will be commercialised and available for purchase alongside conventional meat. When that time comes, Australia will require a robust and appropriate regulatory framework that is evidence-based and provides clarity for consumers.

Exports

Australia has a well-deserved reputation for quality and safety, supplying some of the world’s best food and beverages. Local and international food producers have the opportunity to leverage this reputation to export alternative proteins.

Food safety and security is a high priority in major Australian export markets such as China, which recently grew to Australia’s second largest trading partner in the food and grocery sector. Chinese consumers are increasingly demanding “fresher foods of higher quality with a stronger safety record” – foods that Australia continues to supply.

As the country’s number one food and grocery export, the Australian conventional meat industry could leverage its production expertise and distribution channels to fast-track the growth of Australian-made alternative proteins into export markets, similar to Tyson Foods’ investment in alternative proteins.

Countries across the Asia Pacific continue to demonstrate a strong appetite for plant-based products, with new vegetarian and vegan product launches in South East Asia between 2012 and 2016 increasing by 140 percent and 440 percent respectively. The combination of positive consumer sentiment towards Australian products, lack of existing alternative protein exports, growing demand for healthier, sustainable options in Asian markets and increased investment in new protein options, presents an immediate export opportunity for Australian-made alternative proteins as an extension of the meat category.
CONCLUSION

Intensive animal agriculture was enabled by technological innovation, and now technological innovation is responding to market demands by rapidly providing alternatives to conventional, resource-intensive models of production.

For the first time, the conventional protein market is facing disruption. Global protein demand is rising due to both population growth and increases in per capita consumption. This demand is placing enormous stress on our food production system – a system that is approaching its feasible limits – by creating significant environmental, public health and food security challenges. A compounding list of interrelated economic, environmental, social and demographic factors, as well as nutrition-driven preference shifts, are pushing the industry to innovate.1

Given the challenges posed by conventional animal agriculture, slow incremental change is insufficient to meet global protein demand within sustainable planetary limits. Recognising the need for rapid change, the emerging alternative protein industry is taking a fundamentally different approach to meeting humanity’s growing demand for protein. By recreating meat from the molecule up, these innovators are focussed on building a protein market that prizes both sustainability and efficiency.

Promising, emerging proteins still face a number of major challenges as they attempt to scale. To reach their full potential, industry and government will need to support these nascent technologies. Governments have a crucial role to play in pursuing progressive, enabling regulation that supports evidence-based positions, free from influence by vested economic interests. Public and private institutions will need to be incentivised to build ecosystems that encourage investment while fostering innovation and competition.

The challenge of meeting the protein needs of a mid-century population of 10 billion people in an inclusive, sustainable, healthy and nutritious manner is enormous, but achievable. What is clear is that this will not happen on our current, business-as-usual trajectory. Significant transformation of the protein system is essential to achieve the Sustainable Development Goals and to meet the Paris Agreement climate change targets.”  

— WORLD ECONOMIC FORUM
Cell-based meat must still overcome significant engineering hurdles to scale production, become cost competitive with conventional meat, and achieve widespread consumer acceptance. Increasing investment and cross-industry collaboration are speeding the pace of innovation as cell-based meat companies commercialise, however, governments and institutions also have an important role to play in overcoming these hurdles. Australia’s research and development capacities in the crucial areas of stem cell research and regenerative medicine, tissue engineering, bioprocess engineering, food science and product development could contribute significantly to advances in cell-based meat technology and solidify Australia’s position as a global player.

Plant-based meat alternatives are becoming increasingly mainstream and widely available, but remain just a fraction of the overall protein market. Consumer demand is outpacing supply, necessitating increased investment levels to enable product innovation and to facilitate increased production capacity. Opportunities exist for the exploration and categorisation of new proteins as ingredients, and improvements in processing technology to achieve scale.

Although rapid industry growth and its effect on all sectors of the supply chain – from farmers to manufacturers, distributors, and retailers – has yet to be quantified, it is clear that vast opportunities remain to satisfy latent consumer demand for alternative proteins. As the market matures, it will be important to maintain a clear perspective on which of the emerging technologies has the greatest potential. Further research and increased investment in plant-based, cell-based and hybrid products is required to fully explore the opportunities these alternatives offer, and to identify the sector’s socio-economic impacts on the Australian economy.

Australia can capitalise on its strengths in agriculture and science through the exploration of novel crops, new revenue streams and collaborative business models. Primary inputs from Australian farmers can supply Australian manufacturers developing products in the emerging alternative proteins industry, thus growing the national food value-chain and providing further opportunities for export. Government supported, industry-led initiatives to explore ways for Australian producers to capitalise on this opportunity would be both advisable and timely.

The alternative protein sector has arrived, bringing with it the potential for humans to create a healthier, more sustainable food future. The opportunity to provide economic, health and sustainability benefits is compelling; global demand for alternative proteins has been demonstrated, and its steep growth trajectory is expected to continue. Government and business in Australia have a window of opportunity to become a first mover in the Asia Pacific by playing a leading role in advancing the growth of the alternative protein sector. To position itself as a regional leader, Australia must act quickly.

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**INTRODUCTION**


22. Carrington D. Humans just 0.01% of all life but have destroyed 83% of wild mammals - study. The Guardian (UK) [Internet]. 2018 May 22 [cited 2019 Mar 6]. Available from: https://www.theguardian.com/environment/2018/may/21/human-race-just-0.01-of-all-life-but-has-destroyed-over-80-of-wild-mammals-study


PLANT-BASED MEAT ALTERNATIVES


Meat Re-Imagined


10. HNY Research (HK). 2018-2023 Global and regional meat substitutes industry production, sales and consumption status and prospects professionals-prefer-sustainable-brands.html


CELL-BASED MEAT


Meat Re-Imagined


43. Source: developed from unique research by Food Frontier in 2018.


45. Source: developed from unique research by Food Frontier.


