SYNTHETIC FOODS

Synthetic Foods was the feature article in the ANZ Agri Focus December 2016 edition written by our rural economist.

SUMMARY

A new innovation in food production is synthetic food products. Synthetic food is being marketed as more ethical, environmentally sustainable, stable, safe, healthier and diverse than the traditional products they are looking to imitate. Some have already reached the marketplace with success. Others remain in the 'proof of concept' stage.

While many of the potential advantages make sense, it is still very early days. Many benefits are not likely to be as large as claimed and there could be unintended consequences and trade-offs that will only reveal themselves over time and with more research.

Synthetic foods face four key barriers to further progress: commercial scalability; technicalities of creating equivalent imitations; regulation related to the labelling of food and its safety; and consumer response/acceptance.

For New Zealand food and beverage companies there will always be a marketplace for natural products that are produced in a sustainable manner. To defend against new forms of competition (innovation) New Zealand will need to tell this story for every product sold. This requires producing quality products with unique attributes compared with synthetic products, as well as trademarked intellectual property. Other areas of focus are a need to continually strengthen sectors' claims and credentials around animal welfare, environmental sustainability and food safety with appropriate policy and quality assurance programs.

INTRODUCTION

There have been many innovations throughout history that have changed the paradigm of many businesses and society. Some are show-stoppers – the wheel, the internal combustion engine, electricity, railroads, and more recently, computers and the internet. Others have been more subtle but equally important; think about what the creation of spectacles/contact lenses meant for the productivity of some members of society. These innovations created new businesses and opportunities that expanded the production possibility frontier of society (and have driven efficiencies), and often forced incumbents to radically change their own business models. The rate of change across a number of areas these days is staggering and hard to keep up with. Some of the new innovations offer opportunities; others introduce new forms of competition; and some do both.

Reading the daily headlines on the business of food highlights an increasing number of companies looking to produce a range of synthetic, or artificial, foods. The motivations are varied, but all are trying to disrupt, or create new forms of competition to the 'traditional' way of producing food, especially in the livestock sectors. For some nations with limited natural resources, alternative (low cost) food sources are an economic imperative. Many of the livestock examples are looking to create the same products as are served up in any restaurant, or as a home-cooked meal, but without the need for an animal to be involved. But the livestock sector is not the only target, with one recent project beginning to investigate the feasibility of producing synthetic wood too.

Such innovations create a mix of feelings ranging from fascination and intrigue through to dread. Where one might sit on this spectrum probably depends on whether you are a consumer, producer, or venture capitalist searching for the next big thing. For the consumer feelings could be mixed too, depending on social beliefs and cultural attachments to food.

At first blush, if such innovations make it to market at scale they could well sit in the 'show-stopper' category for the New Zealand economy and primary producer businesses. The primary sectors account for 74% of the country's goods exports and some 15-18% of GDP. This means there is much at stake, not just for a number of individual businesses, but the entire economy. If the 'traditional' way of producing food is going to be consigned to history – as the car did to the horse and carriage – then some radical change is forthcoming.

Agricultural innovation and the need for the economy and businesses to adapt are not new. Take wool as an example. Back in the 1950s it used to account for 37% of New Zealand's exports, and sheep farming was a significant proportion of economic activity. Today wool and woollen products account for around 2% of total exports and sheep farming is a much smaller proportion of economic activity. One of the biggest changes through this period has been the inexorable rise of synthetic substitutes at the expense of natural fibres (mainly cotton & wool). Since the 1960s the market share of synthetic fibres has risen from 10% of total consumption to nearly 70% today. Wool's market share has declined from 10% of total consumption to about 1%. While wool is different to food (i.e. worn as opposed to eaten) it is still an interesting case study for what synthetic food could mean.

So we thought it would be worthwhile taking a look at what the emerging field of synthetic/artificial food[1] might mean and the propositions of an increasing number of start-up companies that are attracting a flurry of venture capital. At the outset there are no certainties, given the emerging nature of different innovations and the wide range of biotechnology techniques looking to mimic, or completely recreate, a range of existing food products. Many complexities, a certain amount of extravagant marketing and a number of unknowns mean one is left with more questions than answers. But in many ways that is the nature of the beast when discussing innovation – it never stops and often takes a different direction from first intentions.

[1] We will use the term synthetic for the rest of this article, but both this and artificial can be used interchangeably in most cases.

What we have endeavoured to do is provide some context to some of the questions that pop up when discussing synthetic food. We offer some thoughts on what it might mean for the New Zealand primary sectors and the potential strategies that might be required to fend off a new form of competition.

WHAT IS SYNTHETIC OR ARTIFICIAL FOOD?

A simple definition of synthetic food is: a product that has been produced by biotechnological methods from particular nutritive substances, such as proteins or their component amino acids, carbohydrates, fats, vitamins, and trace elements. The end result is a product that looks to imitate natural food products by recreating appearance, colour, flavour, aroma, texture, nutrition profile and palatability.

Reading the headlines one would be forgiven for thinking only burger patties and a few other animal products are being developed. But dig a little deeper and it seems nothing is off limits.

Synthetic products under development include: steak chips, burger patties, meatballs, hotdogs, sausages, meatless 'chicken' strips, mayonnaise and cookie dough without eggs, scrambled egg replacement, bacon, milk, cheese, yoghurt, ice cream, popcorn, shrimp and cultured leather. Some of the products using plant-extracted nutrients, and/or acellular production methods are already on supermarket shelves offshore. Just about all the products include a mixture of ingredients (both natural and synthetically produced) to be able to adequately imitate key features such as texture, flavour and colour.

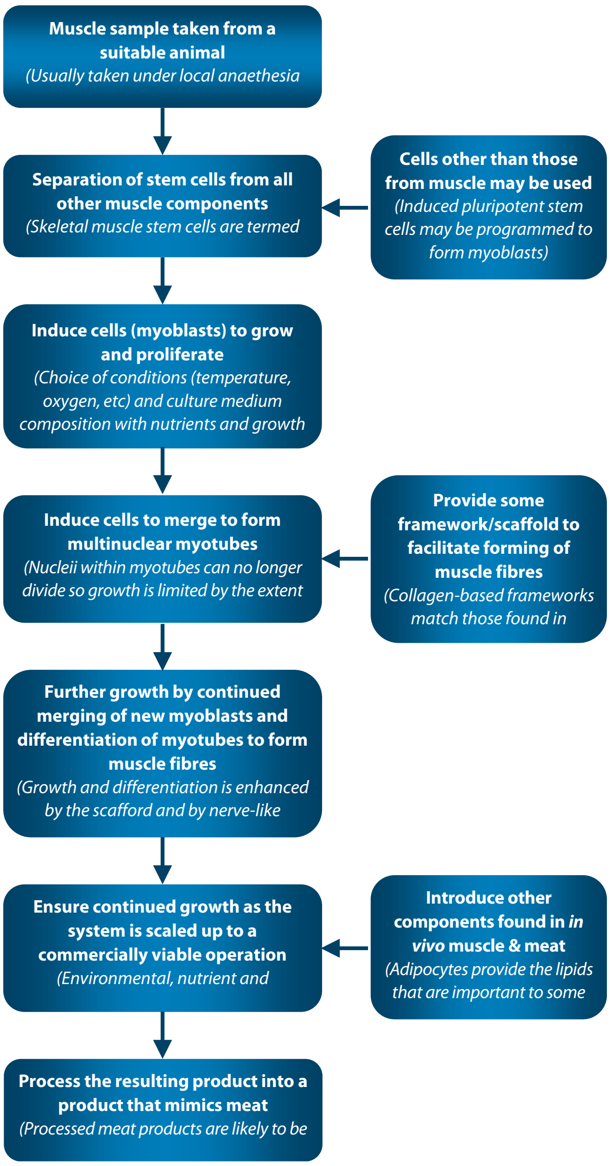
The technologies being used to create such products cover a number of different scientific disciplines, from medical through to food science fields. Broadly, there seem to be three main approaches being investigated/used to produce the components (i.e. proteins, carbohydrates, fats, vitamins and trace elements) to create such products. Once the components have been created further traditional food manufacturing processes are applied to produce a final product.

The three main approaches are: cellular production, acellular production and extraction from plant or animal-based materials. Both cellular and acellular production is about synthesizing food substances. The components, some of which are synthesised together, are then combined with other nutrients to imitate the desired product. This can include recombination with other naturally occurring substances.

Cellular production methods in their most basic form are about taking a number of cells and proliferating them in a nutrient-rich medium. The production methods have different variations. Figure 1 shows the main steps when producing cultured meat, for example. This process involves taking a number of cells from a particular animal and proliferating them in a nutrient-rich medium. After the cells are multiplied, they are attached to a sponge-like 'scaffold' and soaked with further nutrients to allow additional growth to form muscle fibres. They may also be mechanically stretched to increase their size and protein content. Additional components may be added to provide other important nutrients or aspects. The result can then be harvested, seasoned and cooked as a boneless or processed meat, such as a sausage, hamburger, or chicken nuggets.

Acellular production is slightly different in that it uses micro-organisms, such as bacteria or yeasts, to synthesise a range of different nutrients. Essentially, different types of bacteria or yeast are grown on a food (sugar etc) or non-food (petroleum hydrocarbons) medium and through excretion or fermentation different nutrients are created. This process has been used to make substitute products for the likes of egg whites, gelatine and milk proteins. It's essentially the same process that is used to obtain insulin and is similar to brewing beer.

FIGURE 1: PRINCIPLE STEPS TO PRODUCE CULTURED MEAT



Source: Journal of Integrative Agriculture: Cultured Meat from Muscle Stem Cells: A review of challenges and prospects.

The example from the company Perfect Day that has been used to create milk proteins provides some further insight into the process. They took a standard yeast and placed DNA from a cow into it with 3D printing. With the yeast's new DNA 'blueprint' it is then grown on a special mix of plant-based sugars, fats and minerals. This sees the yeast ferment the sugars and create milk proteins in a process similar to craft beer brewing. The final product is then filtered and purified of all yeast.

While the process uses genetic engineering, or a genetically modified organism (GMO) in the form of the yeast to make the milk proteins, the final process removes this material, essentially making it a non-GMO food. However, the end product isn't an exact replica of milk, rather the proteins contained within milk. The proteins are then combined with plant-based (lactose-free) sugar, fats, vitamins, and minerals to form the final product.

The third process used is the extracting and isolating of different nutrients from a variety of plants and animal foodstuffs. Nothing seems to be off limits, but common plants being used include soybeans, peanuts, sunflower seeds, cottonseed, sesame, rapeseed, oil cake, peas, wheat gluten, and other green material from plants. Animal protein extracts are being derived from casein, fish, krill, and other marine sources. To identify suitable nutrients to imitate a certain food product the basic biochemistry of each is first studied to understand their characteristics and possible applications. The promising ones are then tested in a variety of recipes (or formulations) to see how they perform.

An example is Hampton Creek, which has analysed more than 7,000 plant samples and identified 16 proteins that might prove useful in food applications. Several are already being used in its commercial food products, including a type of Canadian yellow pea in its mayonnaise instead of eggs. The company has been looking for proteins with functional properties such as foaming, gelling and moisture retention. Mayonnaise, for example, requires a substance that binds the right amount of oil with water to create a stable emulsion. For its version in stores the company tested more than 1,500 different formulations. Advances in profiling technology are lowering the cost and allowing a much wider range of extracts to be tested more quickly and cheaply.

While all three approaches have produced trial products, the latter two are producing commercially available products already. In reality, acellular production and extraction, followed by recombination of ingredients, have both been used to create traditional foods/beverages, medicines and other health products for some time. But it now seems these techniques are being adapted/expanded with other new technological developments (such as 3D printing of DNA into yeast) to produce a wider range of nutrients that can then be recombined, including with natural products, to imitate and create a whole new range of food products.

WHAT'S THE COMMON PITCH?

You name it and the new start-up companies in the synthetic food space are looking to claim it. There are numerous claims that the new synthetic products are more ethical, sustainable, stable, safe, healthier and diverse than the traditional foe they are looking to replace. We discuss five key areas that are often focused on.

Environmental sustainability

Producing a more environmentally-friendly product seems to be one of the main motivations advocates cite for the development of synthetic livestock and seafood products. The common pitch is that livestock sectors use a vast amount of land, water and fertiliser as well as producing a large proportion of the world's greenhouse gases and other environmental externalities (i.e. eutrophication of waterways etc). Seafood developments are driven by declining wildlife stocks from over-fishing and pollution. This is leading to a rise in aquaculture to fulfil demand, but this is perceived as resource intensive. With demand for products from both sectors expected to increase over the coming decades ahead driven by population growth, westernisation of diets and income growth in emerging economies, it's assumed the world's natural resources won't be able to cope.

Animal welfare and ethics

The main processes used to produce synthetic food primarily use no animals and therefore avoid animal welfare (and other ethical) concerns associated with consuming livestock products. Cultured meat requires only the harvest of stem cells, which would affect only a small number of animals and can be done in a humane manner. This means there are no animal welfare issues a consumer needs to be concerned about.

Of course consumers already have access to a number of products under the vegetarian, or vegan categories that avoid ethnical concerns. What is different with the majority of synthetic food start-up companies is they are not targeting the small percentage of the population who live largely on a plant-based diet already. They are after consumers who love meat, seafood and dairy products, and that means replicating the meaty, cheesy or creamy flavours and textures that they crave while enabling them to not feel guilty about the exploitation of animals.

Healthiness

As synthetic products are being created from 'the ground up' the nutritional profile can be tailored to deliver health benefits. This means any product's macro (protein, fat, carbohydrates) and micro (vitamins, minerals, iron etc) nutrients can be altered to deliver a consumer's exact nutritional preferences determined by factors such as demographics, physical activity, health requirements, gender etc. This makes synthetic food potentially healthier than conventional products where the nutritional profile can be less easily changed and often has much more variability (i.e. fat content of different animals).

Safe

With synthetic food being created in a controlled environment there is said to be a reduced risk of various pathogens/diseases (e.g. E.coli) contaminating food. When animals are not used there is also no risk of antibiotics, hormones, arsenics and vaccines associated with conventional livestock production systems entering the food chain. The overuse of antibiotics in animal production stems primarily from their regular use in intensive housed production systems where it is required to control infectious diseases that are associated with keeping animals in confined spaces. So it is less of an issue for New Zealand sourced product.

Creation of new types of food

Some suggest the new synthetic foods of the future will create new flavours, textures and sensual experiences that conventional food cannot. This will open up a whole new world of different food experiences.

WHAT ARE SOME OF THE COUNTERPOINTS?

There is a lot to admire in some of the start-up companies' marketing efforts to attract new venture capital to their businesses. Many New Zealand companies could no doubt learn a thing or two. But if one actually scratches below the surface of the marketing and media hype it becomes much more complex, with a number of counterpoints and trade-offs that are often not acknowledged.

Environmental trade-offs

Many of the environmental sustainability arguments make intuitive sense. On a very primitive level conventional livestock production requires nutrients and energy for biological structures to live, move and reproduce. This includes growing bones, the respiratory system and digestive systems, skin, and the nervous system. Thus if you don't need to use nutrients, or energy for all these biological structures to produce meat, seafood or milk, then the alternative process should be less resource-intensive (or more resource efficient, depending on your point of view).

In the United States, producing 1kg of animal live weight typically requires 10kg of feed for beef, 5kg for pork and 2.5kg for poultry. Translating this into the final product that is bought at the supermarket multiplies these numbers further (i.e. live weight to retail weight). Using cellular or acellular production methods that use sugars, bacteria and other inputs to produce synthetic replacements – well certain components at least – should theoretically be more efficient.

It's the same with plant-extracted nutrients. One study[2] estimated 45% of the world's grain harvest is diverted to meat production. If current crop production used for animal feed and other non-food uses (including biofuels) were targeted instead for direct consumption, some 70% more calories would become available. This would potentially provide enough calories to meet the basic needs of an additional 4 billion people. Obviously not everyone wants to eat such a diet and from a nutritional point of view livestock and seafood products can provide a number of important nutrients; hence the focus on synthesising, extracting and recombining to make imitations with similar nutritional profiles.

But much remains hypothetical in nature and not well backed up with comprehensive evidence, or commercially proven models that can then be scaled and compared with the livestock sectors in their entirety. Often the global livestock sector's entire environmental footprint is quoted with little other context provided alongside, such as what the entire footprint of replacing this might look like, other potential environmental externalities created, and potential trade-offs. This is in part due to the emerging nature of the different innovations.

One study[3] quoted many times in various stories and research suggested growing meat in factories – or, one day, in your home – is estimated to use up to 45% less energy, 99% less land and 96% less water than traditional farming practices, as well as produce 78-96% fewer greenhouse gases. However, the research used a hypothetical example of just one technique (cyanobacteria as the source of nutrients and energy) being investigated to produce cultured meat. The full scope of the lifecycle analysis also appears somewhat limited and it wasn't overly clear if like-for-like was being compared. For example it didn't appear to include the inputs of key pieces of equipment such as the bioreactor, concrete ponds used to grow cyanobacteria and other important equipment, in its lifecycle analysis. The reason given was the possibility to recycle much of the equipment for other purposes when the plant was decommissioned. But to us these are key inputs and therefore at the very least a depreciated element of the inputs required to construct a commercial operation should be attributed to producing cultured meat, as this is the primary use of such investment.

The analysis also only went up to the factory or farm gate and therefore doesn't cover the whole life cycle of end products. The complete coverage of the supply chain in lifecycle analysis is very important when comparing between different products and markets. This is highlighted by the initial food miles debate New Zealand exporters faced in the United Kingdom market that was subsequently debunked when full lifecycle analysis of the entire supply chain was undertaken.

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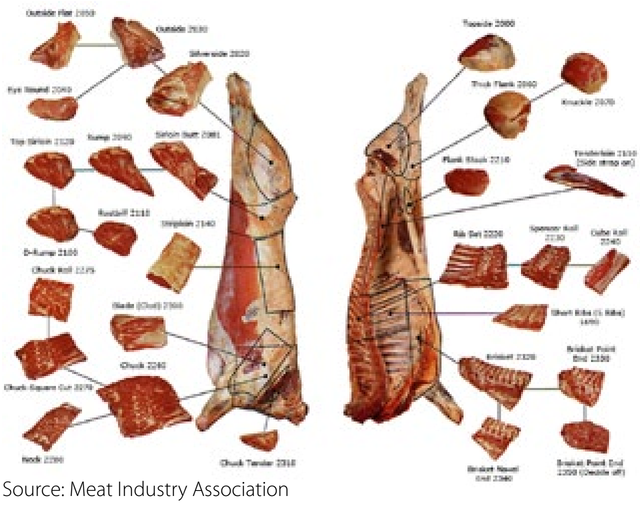
[2] "Leverage points for improving global food security and the environment." *Science* 2014

[3] "Environmental Impacts of Culture Meat Production" by Hanna L Tuomisto and M. Joost Teixeira de Mattos. 2011.

FIGURE 2: CUTS FROM A BEEF CARCASS



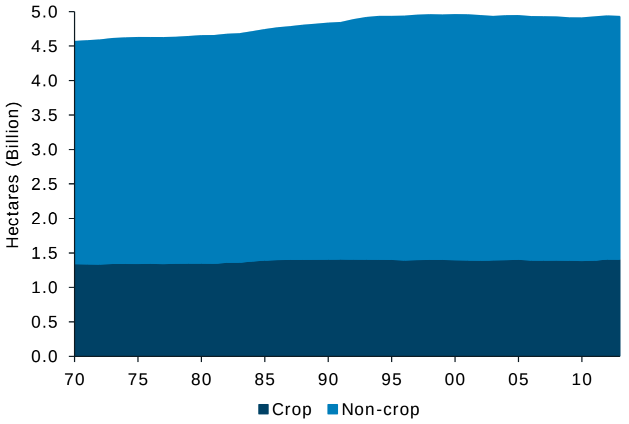
Source: Meat Industry Association

In the case of an animal there is a range of end products from steaks, chops, offal products, skins, hides etc that are produced. In the case of this study an assumption was applied that the entire animal is rendered to its base components (i.e. protein, fats etc) for comparison. The reality is actually completely different. It's likely that the cultured meat would need other macro and micro nutrients blended with it to imitate the real deal too. So there appear to remain a number of unknowns and the need for further research on the lifecycle of such innovations – something acknowledged by the authors of the study itself, but often lost in the headlines of news stories.

Intuitively it seems less land would be used by the three main techniques to produce synthetic food, but in many cases the difference is unlikely to be as great as some suggest. This is due to the need to extract and/or source a range of other nutrients that are then recombined with the synthetically produced components. There is also the need for a biomass to grow synthetically produced components. This means most land that is currently planted with various crops would likely continue to remain in production if these processes are scaled up. The land could be farmed under a potentially different range of crops, depending on their potential use and fit with locally specific factors, such as soil type, topography, rainfall, climate and disease pressures.

In the case of livestock farming that occurs on more marginal grassland areas (i.e. beef and sheep), this is often the most efficient use of this land as it isn't suitable for producing crops. Indeed the growth in the global area of arable land has slowed recently, suggesting losses from urbanisation and environmental degradation concerns (i.e. further deforestation) are offsetting the push into more marginal growing areas. This means grassland areas will still be a critical part of the overall food production equation moving forward.

FIGURE 3: GLOBAL AREA OF AGRICULTURAL LAND



Source: ANZ, FAO

While there would be some obvious biodiversity and eutrophication benefits of reverting grassland areas to a more natural state, or using it for other environmental services (i.e. carbon sequestration), the overall gain and other trade-offs can't be completely ignored either.

From a biodiversity point of view the conversion of grasslands to a more natural state might benefit some species, whereas others may suffer (depending on the area). Using forestry for carbon sequestration provides different trade-offs too. Biodiversity under non-native forestry when compared with a natural state can have a similar impact to using the land for livestock. Forestry can also cause sedimentation during harvesting and the early stages of re-establishment.

The other aspect of letting land revert to a more natural state in some areas is the deep cultural identities many farming communities derive from their landscapes. While many of these landscapes are entirely artificial when compared with their natural state, some have been this way for hundreds or even thousands of years. Changing this would have a big impact on these communities' cultural identities and employment.

Crusaders for synthetic food often try to target industrialised food production systems, but the creation of economically competitive alternatives would likely have a larger impact on subsistence farmers. It has to be remembered food production continues to employ the largest proportion of the globe's population. Indeed some 2.5 billion people (36% of world's population) are recognised by the FAO as deriving a living from agriculture. Emerging countries account for a significant proportion of this and, from a global livestock production point of view, they are often recognised as operating at the least efficient end of the scale. So potentially they could face the greatest economic and social risks from synthetic foods.

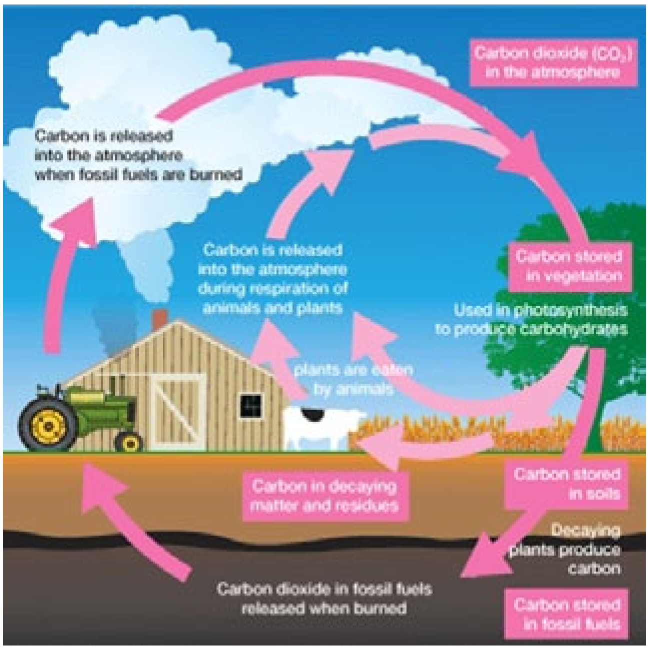
There are other areas of challenge too, for the likes of water usage, nutrient loss and greenhouse gases. The debate around each is complex when you examine the intersection of environmental science, policy and economics.

Take water usage/footprints as an example. A properly prepared water footprint will include green water (rain feed), blue water (abstracted) and grey water (dilution or disposal), and should include the water footprint of brought-in feed, wherever it is sourced from. Green water includes all the natural rainfall on land used for livestock production. In areas of high natural rainfall and run-off it's debatable to what extent all this should be incorporated into lifecycle analysis as no matter what the land use, it's still likely to be available and in excess supply. Of course this is regionally specific, as forestry and vegetation can change climate patterns, but in the case of New Zealand, made up of relatively small islands in the Southern Pacific Ocean, our weather pattern is much less dependent on such things.

In reality the use of freshwater and its quality are locally specific matters. This means local regulation plays the most important role in ensuring fair allocation of freshwater between priority uses and adequate quality outcomes for future generations. This philosophy was embedded in New Zealand's National Policy Statement for Freshwater Management in 2014. Various regional councils are now at different stages of implementing the changes.

So making global comparisons of the lifecycle of water for different products seems rather meaningless from both an environmental and consumer point of view. Where it makes more sense is greenhouse gases – this is a global issue. Under the current global framework for carbon accounting, livestock production accounts for a significant proportion of total greenhouse gases. But even this is more complex than first meets the eye, due to the treatment of methane gas (a significant proportion of the livestock sector's contribution to total greenhouse gases) under the current framework, and other carbon accounting quirks (such as the role carbon sequestration in soils can play).

FIGURE 4: ILLUSTRATIVE CARBON CYCLE ON-FARM



Source: ANZ, AgResearch

In brief, methane has a higher warming factor attached to it than carbon dioxide, but it is also a relatively short-lived greenhouse gas (i.e. it breaks down quickly in the atmosphere). That means if you change the policy timeframe, and focus on the long-term impact methane has in addressing peak warming, its impact is overstated. Unless carbon dioxide emissions are reduced rapidly in coming decades, addressing methane emissions will have little impact on the overall magnitude of warming.

Of course such dynamics depend on policy views, because it's the reverse (i.e. methane has a larger impact) if you want to address climate change more quickly. Given its importance to New Zealand's international climate change commitments under the Paris agreement this is currently an area of further research.

The main point for the environmental debate is that any land-use activity that is man-made (i.e. not its natural state) will have some associated environmental externalities, be it biodiversity, nutrient loss etc. Often plant-based crops are held up as a better alternative to livestock. But this doesn't acknowledge that some grazing land isn't suitable for crop production due to soil type, topography, rainfall, climate etc. Additionally, all the various crops farmers grow around the globe each produce their own environmental externalities. In many cases these can be just as damaging, if not worse (i.e. pesticides), than livestock grazing on extensive pasturelands. This is highlighted by the comparisons of different environmental externalities produced by various US biofuel crops in Table 1 on the next page.

So while emerging synthetic food techniques intuitively feel like they could be more environmentally efficient than traditional production systems, it's not as straightforward as the headlines might suggest, nor are the gains likely as large. It's more likely to involve different trade-offs and other unintended consequences that wouldn't be seen until something is expanding and operating at scale (e.g. palm oil).

Safety

The other area of debate is around whether synthetic foods are actually safer and healthier when the technology and science to produce them is often at the more extreme edge of manipulating nature. In reality many things man-made are a manipulation of the natural environment to solve human ills and improve lifestyles. It's just a matter of how far this is taken and the potential trade-offs that might exist as you move along the continuum.

The reality of the science and technology being explored means without more research and testing it's impossible to say what the health and food safety outcomes might be. Often, it takes a while when introducing changes to food sources for problems to show up. When scientists talk about cultured meat allowing the biochemical composition of meat to be changed, for instance, by increasing the content of polyunsaturated fatty acids to make it a healthier or a specialised diet product, this raises a number of questions. Could this create new pathogens, superbugs, and/or resistance to certain medicines? What could consuming

TABLE 1: ENVIRONMENTAL EXTERNALITIES FROM DIFFERENT US BIOFUEL CROPS

How green are biofuels?

Biofuels are getting a bad rap as stories of rising food prices and shortages fill the news. But the environmental, energy and land use impacts of the crops used to make the fuels vary dramatically. Current fuel sources – corn, soybeans and canola – are more harmful than alternatives that are under development.

FUEL SOURCES								
		Greenhouse gas emissions* Kilograms of carbon dioxide created per mega joule of energy produced	Use of resources during growing, harvesting and refining of fuel				% of existing US crop land needed to produce enough fuel to meet half of US demand	
Crop	Used to produce		Water	Fertilizer	Pesticide	Energy		Pros and cons
Corn	Ethanol	81-85	high	high	high	high	157-262%	Technology ready and relatively cheap, reduces food supply
Sugar cane	Ethanol	4-12	high	high	med	med	46-57	Technology ready, limited as to where will grow
Switch grass	Ethanol	-24	med-low	low	low	low	60-108	Won't compete with food crops, technology not ready
Wood residue	Ethanol, biodiesel	N/A	med	low	low	low	150-250	Uses timber waste and other debris, technology not fully ready
Soybeans	Biodiesel	49	high	low-med	med	med-low	180-240	Technology ready, reduces food supply
Rapeseed, canola	Biodiesel	37	high	med	med	med-low	30	Technology ready, reduces food supply
Algae	Biodiesel	-183	med	low	low	high	1-2	Potential for huge production levels, technology not ready

*Emissions produced during the growing, harvesting, refining and burning of fuel. Gasoline is 94, diesel is 83.
Source: Martha Groom, University of Washington; Elizabeth Gray, The Nature Conservancy; Patricia Townsend, University of Washington; as published in Conservation Biology

such an unnatural product over a long period of time mean for overall health (i.e. would there be other unknown longer-term side effects)?

As one study[4] pointed out, the process of cell culture can never be perfectly controlled and some unexpected biological outcomes could occur. For instance, epigenetic[5] modifications could occur during the culture process with unknown potential effects on the resulting product (i.e. muscles in the case of cultured meat) – and human health when consumed.

This same question raises its head for other synthetic foods that are produced by a genetically modified organism, or have an unnatural nutritional profile. To answer these questions and alleviate both consumers' and regulators' fears of the unknown it will take a lot of research and rigorous testing – similar to the introduction of a new medicine. The reality is that until this occurs for an extended period of time – some might say a lifetime, given humans' different needs and developmental stages as we grow and then age – consumers and society are likely to remain sceptical.

Not all nutrients are created equal, raising the question of true direct comparability between synthetic foods and the traditional food they are looking to imitate. For example, in the case of plant-extracted imitations, not all foods contain the same type of protein or iron. Meat, eggs and dairy products are considered complete in high-quality sources of protein that provide the full package of essential amino acids needed to stimulate muscle growth and improve weight management. Plant proteins such as grains, legumes, nuts and seeds are incomplete proteins, in that they do not provide sufficient amounts of essential amino acids. In fact, research indicates that increasing consumption of high-quality complete proteins may optimise muscle strength and metabolism, and ultimately improve overall health.

Lean meats also contain heme iron, which is much more easily absorbed by the body than non-heme iron found in plant foods. Heme iron is an important dietary component for promoting cognitive health, including memory, the ability to learn and reasoning. It is particularly beneficial for growing children because research indicates that some toddlers are at higher risk of iron deficiency, and childhood iron-deficiency anaemia is associated with behavioural and cognitive delays. Yet other studies have also shown heme iron can cause DNA damage and induce N-nitroso compounds, some of which are potent carcinogens with a link to colon cancer.

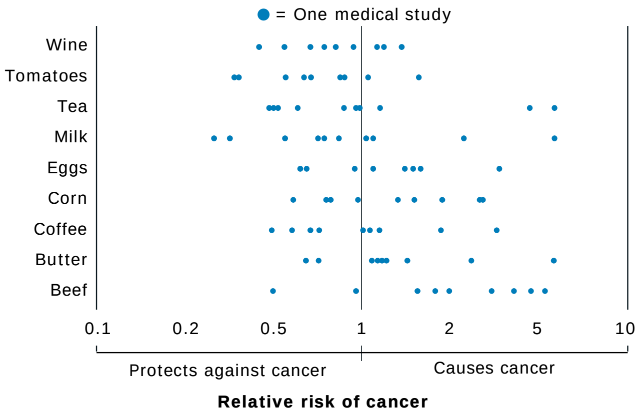
[4] "Educated consumers don't believe artificial meat is the solution to the problems with the meat industry." Journal of Integrative Agriculture. 2015.

[5] Epigenetics studies genetic effects not encoded in the DNA sequence of an organism. Such effects on cellular and physiological phenotypic traits may result from external or environmental factors that switch genes on and off and affect how cells express genes.

Other studies have begun to show all the various supplements that are available in any health shop are much less important if a balanced diet can be eaten. Many of the supplements are providing too high a dosage of their main ingredients and the body hasn't evolved to be able to absorb more concentrated doses that those that occur in traditional food (i.e. staples eaten over many generations).

In the case of food safety, more often than not, single studies contradict one another — such as research on foods that cause or prevent cancer. A recent study[6] demonstrated this by taking 50 randomly selected ingredients from a cook book and seeing what link each has with cancer. Most of the ingredients had research claims of both positive and negative links to cancer. This highlights the sense in the motto 'everything in moderation'.

FIGURE 5: EVERYTHING WE EAT BOTH CAUSES AND PREVENTS CANCER



Source: Is everything we eat associated with cancer? A systematic cookbook review.

This highlights that the truth is usually found somewhere in the totality of the research, instead of the flip-flopping headlines generated from individual pieces of research, or a company touting the next big thing. Such a body of research on the proposed health and safety benefits of synthetic food will take some time to build. Until then we are likely to see a cautious approach from both regulators and consumers on the proposed health and food safety benefits of such products.

WHAT ARE SOME OF THE KEY BARRIERS?

Getting beyond the sales pitches of the various proponents of synthetic foods, there are some key barriers faced to widespread adoption, especially for products that use cellular or acellular production techniques. These centre around commercial scalability; technicalities of creating equivalent imitations; regulation related to the labelling of food and its safety; and consumer response/acceptance.

Commercial scalability

Quality information on this area was very sparse and tightly held, for obvious commercial reasons. The consensus seems to be that new technologies that use cellular or acellular production techniques to produce meat and dairy imitations are mostly still in the 'proof of concept' stage. A few of the leaders appear to have completed the 'proof of concept', but now need to prove they are commercially scalable, the end product is comparable with the traditional equivalent, and there is an actual market.

This means the commercial viability of such technologies is not yet clear. The headlines from various companies suggest rapid improvement is being made, but academic research suggests many barriers remain. The truth is likely to lie somewhere in the middle with the academic research likely only just catching up with commercial reality.

It might very well be that the decrease in costs of resources, labour, and land is offset by the extra costs of a stricter hygiene regime, stricter control, computer management, extra research/development costs and capital costs to develop a large enough bioreactor and other required equipment. Ultimately its looks like we will have to wait and see.

Further along the continuum of commercially viable products are plant extracts. This was highlighted by the recent launch of the Impossible Foods burger and Hampton Foods mayonnaise that doesn't use eggs. The release of the Impossible Foods burger has been tightly controlled to select restaurants to ensure the product is prepared properly (correct preparation is critical to the product's ability to replicate a traditional burger's appearance, flavour, aroma, texture and palatability). The complexities of the different elements that have to be bought together for the Impossible Foods burger mean it is priced at the premium end of the market, whereas the Hampton Foods mayonnaise is more mid-market as the complexities beyond finding the right formulation to replace eggs in mayonnaise are less.

It seems companies are currently targeting products where there is a mix of components used to form the final product. This is for two main reasons:

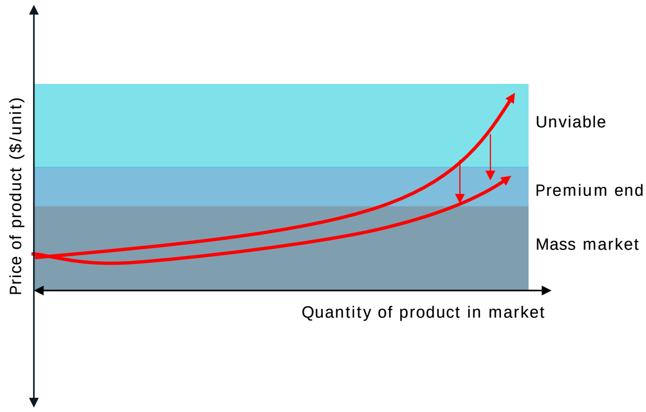
- The technology has not yet been discovered to completely reproduce identical livestock products such as milk in its entirety, or specific cuts of meat.
- The synthetic/substitute components currently being produced need to be mixed with a range of other ingredients to replicate consumers' familiar sensory experiences with a particular product (i.e. the same creamy taste of mayonnaise).

Other barriers aside, this highlights near-term competitive pressure from such technology changes are initially likely to be for specific ingredients and food categories. At the moment most products are being pitched at the premium end of their respective food categories. This implies a higher

[6] Is everything we eat associated with cancer? A systematic cookbook review. The American Journal of Clinical Nutrition by Jonathan D Schoenfeld and John PA Ioannidis.

cost of production for those that are market-ready. Many of the categories being targeted are ultimately more mass market in nature though.

FIGURE 6: THEORETICAL COST OF PRODUCTION CURVE AND IMPACT ON MARKET POSITIONING



Source: ANZ

Putting aside other barriers, how quickly and successfully these products gain market share will be a function of new innovations, technological advance, and supply chain/ process improvements to reduce their cost of production and move them toward the mass market of the targeted food category. While you could draw parallels with what has happened with shale oil becoming the marginal producer in the oil sector, the technology involved and the vast and diverse nature of the food market means this comparison is not so relevant (i.e. the food market currently offers a great deal of choice, meaning consumers can already more easily substitute between goods for whatever reason).

Technicalities

Completely reproducing an existing product's appearance, colour, flavour, aroma, texture, nutrition profile and palatability from synthetic components is challenging for a range of reasons. But as highlighted already, some specific ingredients and products have already reached the marketplace. Some of the innovation used to produce these products is not particularly new though. Food manufacturers have long changed the ingredients in their recipes to adapt to different markets, health research findings, regulation and changing societal eating habits. The current advances suggest manufacturers will have more choice moving forward, which would increase their flexibility and provide more competition in the food ingredients part of the supply chain. But this isn't particularly new with the likes of vegetable oils regularly substituted for milkfat for certain products (especially in Asia). Equally there could be new forms of competition in specific food categories too, such as manufacturing-type meat.

But where the rubber really hits the road is the ability to fully replicate a product from synthetic components. This remains some way off with a number of unknowns as to what might actually be feasible.

The likes of cultured meat production face a number of challenges, such as:

1. Identifying the best source of seed cells;
2. Optimising culture media for efficiency and effectiveness;
3. Developing a suitable framework for the cells to efficiently grow and differentiate on;
4. Developing the 'tissue engineering' aspects;
5. Scaling up of procedures to an industrial level; and
6. Ensuring that nutritional value, health-promoting properties and consumer acceptance is at least equivalent to conventional meat.

All these steps have a number of complications. For example, further manipulation of nutritional components involves trade-offs. If too much fat is removed the meat will lose juiciness and texture. If heme iron is removed the meat won't be red, but yellow – the colour of the beef grown in labs. If too much omega-3 fatty acids are added then there will be a fishy flavour. So the technicalities of actually changing the composition of meat to deliver additional health benefits has a number of potential trade-offs.

Regulation

Regulatory regimes are often one of the most important influences in determining the course of technological innovation. Synthetic foods face two major regulatory hurdles in the form of food safety standards and labelling requirements. Both are complex with overlapping features and there is substantial variation between countries. For some of the emerging technologies, governing legalisation doesn't even exist yet, or there are effectively blanket bans (i.e. genetically modified organisms). In some cases there is a gap between actual market practices and regulation too. All these dynamics suggesting regulators will need to play catch-up at some point.

For example in the US, where they seem to have a more liberal approach to synthetic food developments, there are blurred lines of oversight for food labelling and proving a product is safe for human consumption. The USDA regulates meat, poultry and eggs, whereas the Food and Drug Administration (FDA) overseas safety and security of food additives.

One example given of the challenges faced is the 'milk' product to be produced by Perfect Day. To get safety approval the company could show that their product is similar to an existing product that testing has already shown is safe. That's the approach already taken by companies that use microbes and other biotechnologies to produce enzymes and proteins that are added to foods. Because milk proteins, caseins and whey are already recognised as safe, and Perfect Day are looking to create identical replicas, then approval could be feasible. Where it perhaps gets murkier is the use of genetically modified yeasts to produce the milk proteins. In the US this is likely to get approval as they already have genetically modified crops in the food chain. But in other countries, such as Europe, or even China, this is much less likely under present regulatory regimes.

Labelling of the product as 'milk' is also an area of dispute. Under the FDA rules such a product can't legally be called milk as standards stipulate it has to be specifically produced from lacteal secretions from an animal. Hampton Creeks Just Mayo was facing a similar dispute with Unilever who filed a lawsuit against the company's product in 2014 claiming it couldn't be labelled as mayonnaise. This was due to the FDA's legal definition of the condiment saying it should contain eggs. The lawsuit was subsequently dropped amid a consumer backlash with Unilever launching their own 'Hellmann's Carefully Crafted Dressing & Sandwich Spread'. It seems targeted at the type of consumer who might otherwise be buying Just Mayo. Unilever touts the fact that it's an eggless spread and is free from artificial colours, artificial flavours and genetically-modified ingredients.

In this regard regulation is evolving, with the US now developing a national disclosure standard for bioengineered foods. This is anticipated to give food and beverage manufacturers options in disclosing whether a product contains bioengineered ingredients/genetically modified organisms. The form of a disclosure may be a 'text, symbol, or electronic or digital link' according to the initial bill. Companies would have the option of using quick-response (QR) codes, phone numbers or web sites instead of on-pack labelling. But the changes look set to be challenged, with some advocates saying the proposals fall short of what consumers actually expect: a simple at-a-glance disclosure on the package. Time will tell, but such developments will be influential in determining market impact.

While we have focused on labelling and food safety requirements, there are other regulatory hurdles in the development of synthetic food technologies that sit at the more extreme end of manipulating nature. This includes the likes of trial and licensing requirements for the use of genetically modified organisms. It's understood the European Union has somewhat of a de facto ban on genetically-modified organisms. The US has not banned genetically modified animals from entering the food chain, but is yet to approve any such products for human consumption. So in short, how regulatory regimes progress on a number of fronts will be critical in determining the development of synthetic food and its place in the food market.

Consumer reaction

The consumer response is the ultimate test. Research and surveys on the topic seemed to vary substantially between finding there is limited appeal through to unlimited opportunity! Until more products are in the marketplace it will be difficult to judge how consumers might actually respond.

The main consumer barriers seem to centre around four factors:

1. Perceived 'unnaturalness' of synthetic foods;
2. Initial reaction of "eww yuck", or the 'frankenfood' perception;
3. Safety/health concerns; and
4. Cultural drivers of food consumption patterns.

Both the perceived 'unnaturalness' and initial reaction are somewhat intertwined. The synthetic production process could put consumers off if it is seen as manipulating and messing too much with nature. This obviously depends on the technology being utilised, with the likes of genetic modification at the more extreme end and plant extracts at the milder end. Some surveys suggest consumers have an initial "eww yuck" reaction, but once more information is provided on a product there is at least a willingness to try it. But even if consumers are willing to try a synthetic-based product this does not reveal much about the likelihood of repeat purchase or a sustained change in eating habits.

Whether consumers can overcome the initial reaction and follow through to a more sustained change is likely to depend on a range of factors relating to affordability, safety concerns, healthiness, cultural drivers of food consumption and a product's performance in recreating what is being imitated. As one study noted,[7] it's likely consumers would take a very cautious approach to new synthetic foods that have not been validated or assessed for their effects on human health. Acceptance would depend on the progressive unveiling of the advantages and/or disadvantages of the product together with guarantees from trustworthy public authorities (i.e. health institutions and professionals) and market participants (e.g. high-profile chefs). Issues such as how safety controls are performed and guaranteed, how credible and transparent the information is, and how regulatory structures and procedures are set up are major challenges in this respect.

Equally there are very strong cultural drivers of food consumption patterns in many markets. Even though the modern food market certainly has a fashion element to it, replacing the Sunday roast, or not using a particular ingredient from Grandma's secret recipe, has often taken generations to change. People have been eating livestock and having meals together for thousands of years. Livestock products in particular are not only prized for taste but also perceived as a force of vitality, strength and health. So while certain products might gain a foothold in specific categories or as a certain ingredient substitute, it's difficult to see synthetic food becoming the new norm any time soon given what has occurred since the dawn of man.

[7] Challenges and prospects for consumer acceptance of culture meat. Journal of Integrative Agriculture. Wim Verbeke, Pierre Sans, Ellen J Van Loo. 2015.

HOW CAN NEW ZEALAND'S PRIMARY SECTORS BEST POSITION THEMSELVES?

The mentality of New Zealand 'feeding the world' in the early 2000s has slowly changed to targeting markets and discerning consumers willing to pay a premium for quality food. Some companies and sectors are further along this journey than others. But the direction is fairly clear when you eye the strategies and investment activity of many of New Zealand's major food and beverage companies.

The food market today is vast, with a huge range of choice. Categories such as natural, grass-fed, pasture-raised, organic and wholefoods will always exist and provide a market that synthetic food can't directly compete in. This means if synthetic food does navigate some of the key barriers outlined above and penetrate the mass market, New Zealand's food and beverage companies will need to pivot further toward our unique points of difference. In the case of the livestock sector this includes naturalness of the product through to the sustainability of the production system used to raise livestock. Seafood this includes similar aspects, including a world-leading quota management system that ensures the sustainability of local fish stocks through the control of harvest levels for each species and area. Telling the story of New Zealand's sustainable production system and naturalness for every product sold would be critical in a world of increased competition from synthetic foods.

Other areas of focus need to be strengthening sectors' claims and credentials around animal welfare, environmental sustainability and food safety. Put simply, if synthetic food companies are using claims in these areas as points of differences to conventionally produced product then New Zealand products need to be world class in all of them to provide consumers with peace of mind. This will require robust quality assurance systems for each facet.

Lastly, producing quality products with unique attributes and trademarked intellectual property will also be crucial. This is what the kiwifruit sector has done with Sungold; the pipfruit sector has achieved with new 'club' varietals that have eating qualities desired by Asian markets; and what Marlborough Sauvignon Blanc represents. Each of these sectors has created a unique trademarked product, and combined with the application of best-practice management from orchard through to end customer this is delivering premium returns in many market segments and versus direct competitors. Similar results, albeit not to the same extent, can be seen for products that have more commodity characteristics like green kiwifruit too. Some of the other sectors have a way to go. For the likes of the meat sector, and especially beef where manufacturing product accounts for some 60% of sales (a key target for synthetic products), there might be a need to look at alternative cuts (i.e. bone-in) and products that can't be so easily replicated with synthetic technologies.

As Charles Darwin said, "it is not the strongest that survive, nor the most intelligent, but the ones most responsive to change". New Zealand food and beverage companies have many unique points of difference that can be leveraged to defend against synthetic substitutes. There will always be a market for natural products, particularly in a world where the population is ageing and becoming more health conscious, but companies can't solely rely on this to deliver sustainable returns. Keeping ahead of the competition requires constant innovation and reinvestment into product development, marketing, production efficiencies, food safety, animal welfare and environmental sustainability.

MORE INFORMATION

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