Making sense of the numbers

Synthetic food: should NZ worry? A scene setter

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Author: Hugh Dixon

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Scene setting

This research aims to add value to the discussion on synthetic foods through an examination of the literature, including the benefits from the technology and challenges yet to be overcome. This information will then be used as part of an examination of the potential benefits and costs to New Zealand from the introduction of synthetic foods.

Interest in developing synthetic foods has been growing since the Intergovernmental Panel on Climate Change was established in 1988 and techniques of culturing stem cells from animals become more widely available in the 1990s. Since the early 2000s a number of international University researchers and early start ups have begun exploring and refining the techniques required to culture stem cells from animals and create a viable synthetic food product.

In recent years recognition by governments and the public that environmental change is required has seen the signing of the 2015 Paris Agreement. This agreement aims to keep global temperatures rises this century to below two degrees Celsius above pre-industrial levels. This in turn has increased interest in synthetic foods, and as a result the number of synthetic food companies has increased. In addition these companies have been able to attract significant investments from big name investors and large food production companies. A significant factor in the rise of these synthetic food companies are promised improvements in the environment with synthetic food products said to require less land, water, and energy to produce, while also producing less greenhouse gases.

With New Zealand among the signatories to the 2015 Paris Agreement, efforts to decrease our environmental footprint has become a larger concern with the general public. This was apparent with the 2017 general election campaigns for both the Labour party and the Greens having a strong focus on reducing New Zealand's environment footprint. With a Labour-New Zealand First Government elected in September 2017, and with support from the New Zealand Green Party, it was no surprise that work on a zero carbon bill was started. As part of their election campaign the Labour party had promised to introduce a Zero Carbon bill, with the aim of reducing New Zealand's net carbon footprint to zero by 2050.

As a consequence of the move to introduce a Zero Carbon bill, plus the scientific advancements made internationally, businesses and organisations within New Zealand have an increased awareness of synthetic foods and those in the primary industries have started to look at the potential impacts of synthetic foods on their industries. One such report is the Beef and Lamb New Zealand's "Future of Meat".

The potential impact of synthetic foods could be significant to New Zealand given that in 2018 the New Zealand agriculture sector contributed almost half of New Zealand's total greenhouse gas production. In addition as of March 2019 dairy exports were worth $14.8 billion and directly employed around 48,600 FTEs (primary production and processing). Alongside dairy, meat exports were worth $7.6 billion and directly employed around 49,000 FTEs (primary production and processing).

Given the considerable research that is occurring internationally on potentially replacing traditional meat and dairy products with lab grown substitutes, and how important agriculture is to New Zealand's economy, it very important that this topic is debated in New Zealand. After all replacing New Zealand's traditional grown meat and dairy, with synthetic foods could potentially reduce the amount of land, water, energy, and greenhouse gas emissions by a significant amount.

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1 Introduction

Over the last five years international start-ups focusing on producing diary and meat products using laboratory processes, have moved to within a few years of full industrial production of their products. This has been led by Mosa Meats and Memphis Meats (meat) and Perfect Day Foods (dairy). These companies are pushing the environmental benefits (less energy, less land, less water, and less greenhouse gas emissions), and health benefits (bacterial and chemical free) of their products over traditional manufactured dairy and meat products.

In New Zealand meat and dairy industries generate around 40 percent of New Zealand's total exports, and from the backbone of our economy, so the introduction of commercial synthetic meat and dairy products could seriously disrupt our international meat and dairy export markets.

Given that in 2018 commercial production of synthetic foods seems inevitable as part of a global solution to the climate change crisis facing the planet, the question my research seeks to answer is:

"Will the introduction of synthetic foods destroy New Zealand's agriculture sector, or provide it with new opportunities?"

With the commercial mass production of synthetic meat and dairy foods still a few years away, this research will seek to answer my research question by undertaking a stocktake of progress to date, examining the potential threats synthetic foods pose to New Zealand dairy and meat sectors, along with the opportunities for the New Zealand diary and meat sectors that could arise from the synthetic meat and dairy foods.

Overall this research will be to help inform the industry of the threat, opportunities, benefits and costs that may arise from the uptake of synthetic foods, so that changes can occur proactively rather than reactively.

This report details my findings from a literature review undertaken in 2018 and 2019 on New Zealand and international scientific and policy literature published on synthetic food, in particular synthetic meat.

This report covers defining synthetic foods; the development of cellular agriculture of which synthetic meat and dairy is a part of; discussing the process used to create synthetic meat; the process used to create synthetic diary; the benefits of synthetic meat and dairy; and lastly the challenges facing synthetic meat and dairy, be they technical, ethical, or political.

2 Definition of synthetic foods

One of the key elements in analysing any issue is to define it. Therefore given I am looking at the opportunities and threats arising from synthetic foods, how do we define them? My review of literature revealed that the discussion on how to and what to define synthetic meat as, at least is still up for discussion.

While the definition of what synthetic meat is still up for discussion, most researchers on the topic have moved to call meat produced in-vitro, cultured meat. This is due to the culturing process that is a key part of the production of in-vitro meat. Therefore I have also used the term cultured meat rather than synthetic meat within this report to ensure the reader is not confused by the use of two different terms for the same product.

Stephens et al., (2018) noted that while a short account of the history and technological approach of cultured meat can be written, it remains a challenge to provide a definitive account of what it is. In 2010 Stephens argued that cultured meat (then called in-vitro meat) was best described as an "as-yet un-defined ontological object", to capture the way in which this new type of thing, with little in the way of history or precedent, had entered our world to disrupt and sit uncomfortably within the existing ways we categorise and understand what meat is.

An alternative definition is provided by Hocquette (2016), who argues cultured meat is most accurately described as "artificial muscle proteins" (p169) because 'meat' implies maturation inside an animal and the process of slaughter.

While an alternative view provided by Van der Weele & Driessen (2013), would be to define cultured meat not as a final meat product, but as an ingredient that a meat producer could work into a final meat product. Potentially this could be mixed with other ingredients, including plant-based or traditional animal-based meat ingredients. Alternatively, if potential consumers express what has been termed the 'yuck' response, cultured meat could be recognised as simply not fit for consideration as food at.

3 Overview

3.1 Meat Industry forecasts

In 2006 according to the FAO the meat sector consumes eight percent of all the fresh water in the world, and occupies almost one-third of the world's surface that is not covered by ice and permafrost. In addition raising meat currently contributes 18 percent of greenhouse gases to the atmosphere. This underlines data that shows since 1960 that global meat production increased threefold, and suggests that the rise will continue, from 233 million metric tons (Mt) in the year 2000 to 300 million Mt. in 2020 (Speedy 2003; Alexandratos and Bruinsma 2012; Rosegrant et al. 1999).

This is backed by Business Wire in 2018, which expected significant growth at the global scale, with a recent estimate predicting the global protein analogue market to be worth US$46 billion by 2020.

3.2 Cultured food overview

So when will we be able to buy animal-free meat? This was a question asked by Ireland (2017) to Dr Mark Post. According to Post, both Memphis Meats and Mosa Meat, an offshoot of Post's lab, hope to have competitively priced products by 2020. "In terms of commercial sales, I would say in four to five years," said Post in 2017. "It will still be a somewhat expensive burger, around the $10 mark. Another few years of commercial production and the price will start to fall further.

While small scale production on cultured meat has been achieved, large scale production is significantly more challenging, with a key issue being the production of effective and appropriately priced culture media. (Stephens et al., 2018). This culture media is medium used in the laboratories to feed and growth the cells that form the cultured meat.

One of the driving goals behind cultured meat and dairy are the altruistic and environmental goals of reducing the amount of land, water, energy and greenhouse gases produced by the current meat and dairy industries. This is noted by Stephens et al., (2018), who stated that it is also clear that the current set of cultured meat groups are motivated by altruistic or social and environmental goals and work to develop innovative approaches that maximise potential benefit. However there is no guarantee that these motivations will be shared and pursued by future cultured meat producers, and we are not yet convinced that the benefits are necessarily inherently embedded within the technology, as could be argued.

This warning is overlooked with the focus on the potential benefits that can be delivered by the technology and the initial businesses who are driven by these altruistic or social and environmental goals as much as profit. But the question that should also be posed is what the world will look like if these technologies are used with the sole focus of generating profit.

Again this is noted by Stephens et al.,(2018) stating that it is worthwhile to remain mindful of the possibility that we could see a situation in which we have an economically-viable cultured meat sector that does not deliver all of the more altruistic or social and environmental benefits currently associated with the technology. For example, net global reductions in greenhouse gases or animal slaughters may not be delivered if livestock meat production is not reduced as cultured meat production increases.

While currently the businesses and minds behind cultured food technology are focussed on reducing land use, water use and greenhouse gases associated with the dairy and meat industries, another questions is how far could these industries go to replace the current diary and meat industries?

Ford (2014) offers an interesting thought on why he believes that we will not completely abandon the meat and dairy industries, in favour of cultured production. Ford notes that rearing livestock and grazing animals is of importance to us in maintaining the environment. The countryside largely owes its appearance and its equilibrium to the grazing of herbivores, and the rearing of sheep and cattle with (to a lesser extent) goats and pigs in maintaining this environment in a form to which our civilisation has become accustomed. Although we think of areas like the lush meadows of Germany and the wild vistas of the English Lake District as ‘natural and unspoiled’, they are entirely artificial. These romantic landscapes are the result of land management and grazing of farm animals over thousands of years. The alternative – re-forestation – would deny the public open landscapes for recreational purposes and the cover of widespread woodland could even pose a security problem.

4 Cellular agriculture

The process of producing cultured meat and dairy falls within the wider field of cellular agriculture which according to Stephens et al., (2018) encompasses a set of technologies to manufacture products typically obtained from livestock farming, using culturing techniques to manufacture the individual product. There is still debate as to exactly how cellular agriculture should be defined, and which (proposed) products fit within or beyond this definition. However, within the community associated with cellular agriculture there is some agreement that it can be divided into two types that here we term tissue engineering-based (meat) and fermentation-based cellular agriculture (dairy), grouped by the production method used.

Fermentation-based cellular agriculture manufactures products by fermentation using bacteria, algae or yeast that have typically been genetically modified, by adding recombinant DNA, so they product organic molecules. These molecules can be used to biofabricate familiar animal products (e.g. casein (used for milk), and collagen (used for leather)).

Tissue engineering-based cellular agriculture includes cultured meat and leather systems in which cells or cell lines taken from living animals are tissue engineered in an effort to produce useable tissue with minimal quantities of animal tissue input compared to livestock methods in which the cells themselves form the product. Starting material, i.e. the cells, can be taken from an animal using a biopsy procedure or a genetically-modified cell line could be produced that only requires animals from which to source the original cells.

Lastly Stephens et al., (2018) notes that a key feature of both forms of cellular agriculture products is the aspiration to produce what we term ‘biologically equivalent’ products to the livestock versions. This can extend to targeting molecularly and genetically identical material that delivers viscerally equivalent eating or usage experiences. It is the goal of biological equivalence that separates cellular agriculture from a new wave of plant-based protein analogue projects including Beyond Meat and Just's egg-like products that also seek ‘viscerally equivalent’ experiences but absolutely avoid biological equivalence.

5 Cultured meat process

Overall two major technology approaches have been identified to culturing meat, these are the **self-organizing technique** and the **scaffold-based technique**. The first technique involves the use of an explant from the muscle of a donor animal which is then proliferated in a nutrient medium. The second technique involves suitable stem cells (embryonic myoblasts or adult skeletal muscle satellite cells) which can be obtained from a variety of tissues, being attached to a scaffold or a carrier and then perfused with a culture medium.

Regardless of the technique used to produce the cultured meat, the process as outline in Figure 5.1 is the same. As shown in the figure Cyanobacteria biomass is cultivated then sterilized, before the bulk of it is used to the muscle cell cultivation process, along with growth factor (or serum media), vitamins and cell cultures (of the particular animal to be cultivated).

Figure 5.1 Cultured meat production process[1]

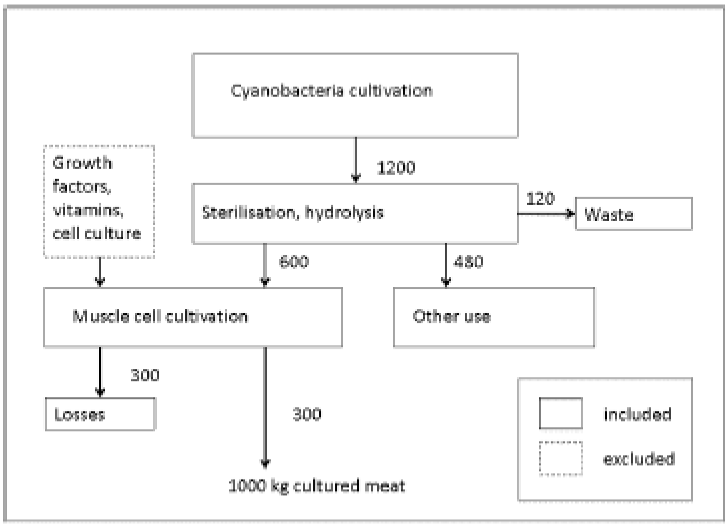

Figure 1: The system diagram of cultured meat production and the cyanobacteria biomass flows (kg DM)

According to Stephens et al., (2018) regardless of the technique used to manufacture the meat it is anticipated that the workforce required in this new industry will require a range of skills and knowledge levels that extend beyond more traditional roles of, for example, agriculturalists and veterinarians to also include chemists, cell biologists, material scientists, chemical engineers, skeletal muscle scientists, technicians, meat scientists, and food technologists.

As noted by Stephens et al., (2018) cultured meat technology involves expanding stem cells then differentiating them into muscle cells. This is typically done using chemical/biological cues in the cell culture media (Langelaan et al., 2011) and mechanical stimulation. However, in the field of tissue engineering there is evidence that physical material properties can be used instead, or as well, and we expect developments in scaffolds to be a necessary part of cultured meat research.

One of the crucial elements of the process is the growth factor or serum used to feed the cell cultures and enable them to grow. As noted by Cocke (2005) traditionally, the medium employed for culturing the skeletal cells comes from an animal source; serum-based medium from adult, newborn or foetus. Complicating things is the fact that as the process enters the differentiation and

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[1] Tuomisto, & de Mattos, 2010

maturation phase from the proliferation phase, the changing demands of the cells (muscle) may require a change in the formulation of culture media. The external growth regulators and promoters can be added from transgenic organisms producing recombinant proteins (Houdebine 2009).

There are two parts of this process that is limiting the volume of meat able to be produced. The first of these is the growth factor or serum that is used to fee the cells. According to Ireland (2017) that successful serums (the nutrient-rich ‘serum’ that feeds the cells) have been a cocktail of sugars, amino acids and animal blood. Not only are blood-based serums a source of worry for vegetarians and vegans, but Dr Mark Post has stated that “there would not be enough serum in the world to grow all the cells you need to mass-produce meat”.

In 2002 Gilchriest and Lorenz (2002) undertook a number of experiments to determine the growth generated by different formulations of culture media. In these experiments they placed goldfish skeletal muscle explants in diverse culture media and observed a varied pattern in growth, with regard to increase in surface area over 7 days. The results based on the medium were as – fetal bovine serum 13.8%, fishmeal extract 7.1%, shiitake extract 4.8%, maitake extract 15.6%. The results of these experiments show that fetal bovine serum proves the greatest growth apart from the maitake extract. This high growth generated by the fetal bovine serum is the reason why cultured meat is generally grown using fetal bovine serum. But as pointed out by Dr Mark Post manufactures will need to move away from using fetal bovine serum to another culture media in order to reduce the reliance the cultured meat industry would otherwise have on the meat industry.

The second issue is that the largest existing bioreactor capable of growing cultured meat cells has a volume of 25,000 litres (about one-hundredth the size of an Olympic swimming pool), which Dr Mark Post estimates could produce enough meat to feed 10,000. It’s likely that many more of these would be needed to make a viable meat-processing plant.

6 Cultured dairy process

The process of creating cultured milk in the lab is a simpler process that of meat, this is because milk has a simple chemical structure, it is a compound made up of six proteins and eight fatty acids. Manipulating the ratio of these components allows for the replication of other dairy products, from cheeses to goat's milk. Another possibility is creating lactose-free products, suitable for some people with lactose intolerance.

Overall using genetically engineered yeasts that have been ‘programmed’ to produce proteins or other ingredients found in plants or animals – on an industrial scale, without raising animals will have less impact on the environment.

As an example of how this process works I looked at the process used by Perfect Day Foods, which was reviewed by Steer in 2015 and showed in Figure 6.1. The Non-bovine pathway (YDM) which involves the production of milk proteins by yeast combined with vegetable oil as being developed by Perfect Day.

In a nutshell, Perfect Day takes food grade yeast, and adds DNA sequences (which can be 3D printed using cultured biology techniques) which effectively instruct that yeast to produce proteins found in milk – predominantly casein, but also lactoglobulin and lactoalbumin, the two proteins that form the bulk of whey protein in milk. It then throws them into big fermentation tanks with corn sugar and other nutrients to feed on and sits back while they get to work.

When the microbes have done their work at the bio-refinery, Perfect Day’s dairy proteins – which have the same organoleptic properties as their animal-based counterparters – are harvested via mechanical process and can be used in everything from ice cream to branded fluid milk, protein powders and shakes, yoghurt, pizza and any other product containing dairy proteins. (Watson, 2017)

Figure 6.1 Summary of Perfect Day production system[2]

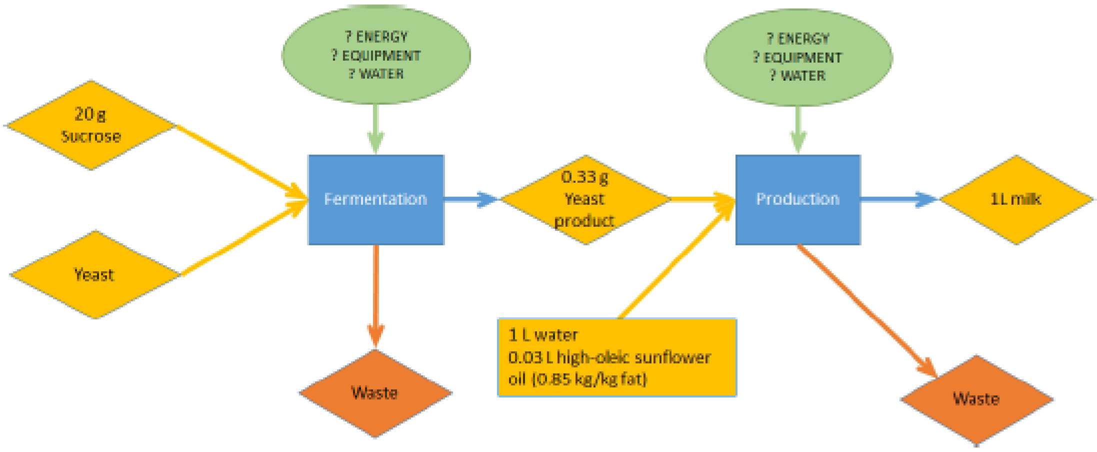

Figure 1: summary of Perfect Day production system

In addition to this summary of the Perfect Day production system, Steer in 2015 compared the production of one litre of milk from Perfect Day to one litre of ordinary milk, to assess the impact of both processes on land, water, energy and greenhouse gasses. Within this production system comparison, the following components are not included in the analysis as noted in Table 6.1:

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[2] Steer (2015)

- The agricultural processes of beet/cane sugar cultivation
- The agricultural processes of sunflower oil cultivation
- Raw material production and processed, acquisition and transport to the Perfect Day Lab
- Yeast culture operations
- The production of perfect day milk
- And the management of wastes and production of heat and electricity.

Table 6.1 Modelled land, water and energy requirements, plus GWP, of producing 1 litre of milk[3]

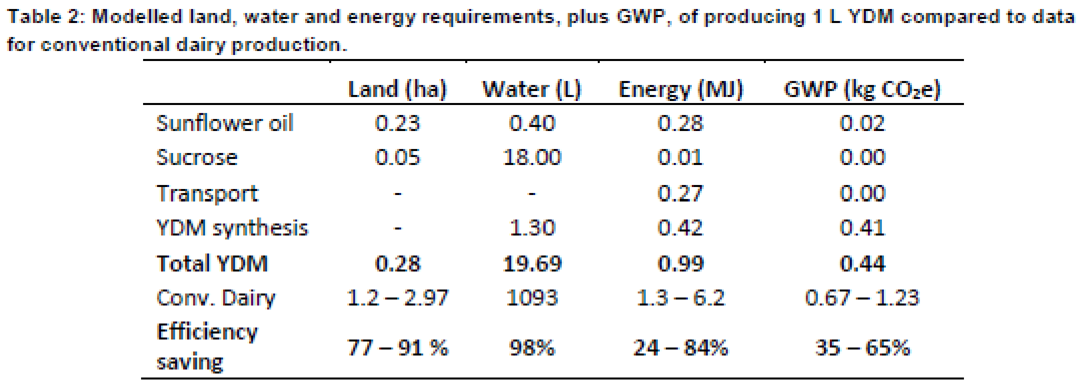

Table 2: Modelled land, water and energy requirements, plus GWP, of producing 1 L YDM compared to data for conventional dairy production.

	Land (ha)	Water (L)	Energy (MJ)	GWP (kg CO_2e)
Sunflower oil	0.23	0.40	0.28	0.02
Sucrose	0.05	18.00	0.01	0.00
Transport	-	-	0.27	0.00
YDM synthesis	-	1.30	0.42	0.41
Total YDM	**0.28**	**19.69**	**0.99**	**0.44**
Conv. Dairy	1.2 – 2.97	1093	1.3 – 6.2	0.67 – 1.23
Efficiency saving	**77 – 91 %**	**98%**	**24 – 84%**	**35 – 65%**

Ryan Pandya Co-Founder Perfect Day sums up his companies push to expand production.

"We've brought in folks with more than 15 years' experience in the dairy industry as well as protein ingredient experts and we now have a team of 25 people. We've also expanded out pilot facilities to 17,000 square feet in Berkeley. The commercial scale facility will also be in America, but the location will depend on the scale partner that we end up signing on, as we want to leverage existing infrastructure and scale up super-fast."

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[3] Steer (2015)

7 Benefits of cultured meat and dairy

Overall cultured meat could deliver reduced water use, greenhouse gas emissions, eutrophication potential, and land use compared to conventional livestock meat production. In addition to these potential environmental benefits, international research has indicated that cultured meat could provide health benefits, along with create new opportunities in the traditional meat industry. All three of these benefits are explored below.

7.1 Environmental

It is the potential environmental benefits that could be generated by replacing conventional livestock meat production with cultured meat production, that are fuelling the current growth and investment into cultured meat production. Overall these environmental benefits provide the largest benefits of the cultured meat industry.

This is because as discussed by Sharma et al., (2015) globally the raising of livestock has a direct role in the emission of methane (CH4) and nitrous oxide (N2O), described as some of the most aggressive greenhouse gases by the World Bank. Livestock farming forms over 8% of global human water use. The farmed animals in the United States produce 130 times the waste as the human population. Conventional meat production systems recycles huge amounts of freshwater, potable water into polluted, wastewater. In addition the vast areas of agricultural land covered by the fodder produced for animals require extensive use of fertilisers, pesticides, herbicides, insecticides and fungicides. This leads to elevated nitrate levels.

Further it has been reported by Goffman (2012) that the manure from industrially farmed pigs includes gases like ammonia, methane, hydrogen sulphide, carbon monoxide, cyanide, phosphorus, nitrates and heavy metals along with over 100 microbial pathogens like salmonella, cryptosporidium, streptococci, and girardia. Indicating that the production of greenhouse gases comes from all livestock production be it (beef cattle, sheep, pigs, deer or other animal farming).

Given the potential environmental benefits of cultured meat in comparison to conventional livestock production, a number of Life Cycle Assessments have been undertaken to try and measure this potential, although all the assessments are based upon hypothetical models of what form cultured meat production might take.

One of the most noted Life Cycle Assessments of the cultured meat production was undertaken by Tuomisto, & de Mattos in 2010. The results of their Life Cycle Assessment are shown in Table 7.1, and shows the overall energy use and greenhouse gas emissions resulting from each stage of the cultured meat production cycle. Overall producing a 1000kg of culture meat would use 26.64 GJ of energy and create 1,508kgs of CO_2 equivalent. The main energy use comes from muscle cell cultivation process with 21.19 GJ used during this process. In addition this part of the process also generated the greatest share of CO_2 equivalents with 1,122kgs.

Table 7.1 Primary energy use and greenhouse gas emissions from producing 1000kg of cultured meat, 2010[4]

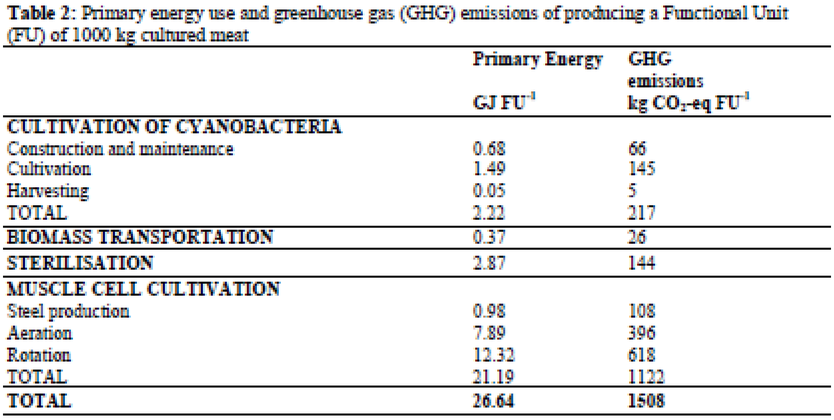

Table 2: Primary energy use and greenhouse gas (GHG) emissions of producing a Functional Unit (FU) of 1000 kg cultured meat

	Primary Energy **GJ FU^{-1}**	**GHG emissions** **kg CO_2-eq FU^{-1}**
CULTIVATION OF CYANOBACTERIA		
Construction and maintenance	0.68	66
Cultivation	1.49	145
Harvesting	0.05	5
TOTAL	2.22	217
BIOMASS TRANSPORTATION	0.37	26
STERILISATION	2.87	144
MUSCLE CELL CULTIVATION		
Steel production	0.98	108
Aeration	7.89	396
Rotation	12.32	618
TOTAL	21.19	1122
TOTAL	**26.64**	**1508**

As part of Tuomisto, & de Mattos research the results of their Life Cycle Assessment was compared to results from earlier assessments undertaken since 2002 across a range of different cultured meat (Beef, Lamb, Pork and Poultry). Their results in comparison to other studies show a much lower environmental impact generated by the cultured beef meat industry.

Table 7.2 Environmental impact of producing 1000kg of cultured meat, various studies, 2010[5]

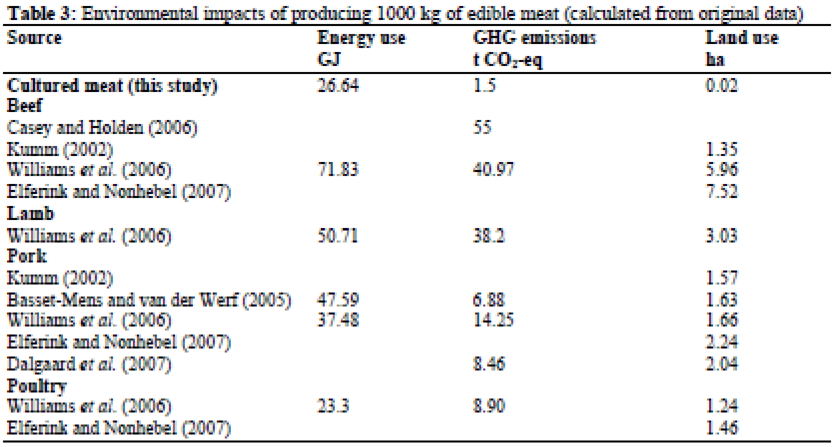

Table 3: Environmental impacts of producing 1000 kg of edible meat (calculated from original data)

Source	**Energy use** **GJ**	**GHG emissions** **t CO_2-eq**	**Land use** **ha**
Cultured meat (this study)	26.64	1.5	0.02
Beef			
Casey and Holden (2006)		55	
Kumm (2002)			1.35
Williams *et al.* (2006)	71.83	40.97	5.96
Elferink and Nonhebel (2007)			7.52
Lamb			
Williams *et al.* (2006)	50.71	38.2	3.03
Pork			
Kumm (2002)			1.57
Basset-Mens and van der Werf (2005)	47.59	6.88	1.63
Williams *et al.* (2006)	37.48	14.25	1.66
Elferink and Nonhebel (2007)			2.24
Dalgaard *et al.* (2007)		8.46	2.04
Poultry			
Williams *et al.* (2006)	23.3	8.90	1.24
Elferink and Nonhebel (2007)			1.46

In later research Tuomisto et al. (2011) compared cultured meat to conventionally produced beef, sheep, port and poultry, finding it involves approximately 78-96% less greenhouse gas emissions, 99% less land use, 82-96% less water use, and 7-45% less energy use, depending upon what meat product is it compared to (although poultry uses less energy).

While Mattick, Landis, Allenby, and Genovese (2015) produced a second comparative study that come to the same finding, though they used a different model for cultured meat production, with the most notable differences being the media production method used and inclusion of a cleaning phase.

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[4] Tuomisto, & de Mattos, 2010

[5] Tuomisto, & de Mattos, 2010

7.2 Health

Research undertaken by the World Health Organisation in 2009 found that there is a correlation between high meat consumption with elevated rates of chronic diseases particularly, diabetes, Cardio Vascular Diseases (CVD) and cancer which, eventually lead to morbidity and mortality. But according to Williams (2012) cultured meat is expected not to pose such a problem as traditional meat. This Williams suggests is because with cultured meat the ratio of omega 6 and omega 3 fatty acids can be modified, therefore helping to create a healthier meat. Currently in the Western World, the ratio of these two is in favour of omega 6, rather than omega 3. This can be done by altering the DNA of the progenitor cells, a step that can be taken care of in the In Vitro Meat Production System (IMPS).

Another area where cultured meat could produce health benefits for the world population is according to Sharma et al., (2015) is through the reduction in the uncontrolled use of antibiotics and other drugs to promote growth in animals used for livestock meat production. Overall this use of antibiotics and other drugs results in human health hazards, particularly of antibiotic resistance. IMPS will reasonably counter this issue as there is no involvement of factory farming and drug feeding in culturing of meat in the lab. In addition Datar and Betti (2010) also asserted that myocyte cell culturing is a solution to the set of health related concerns posed by livestock meat to human health.

7.3 New Opportunities

As stated by Stephens et al., (2018) cultured meat could also provide new opportunities within tradition agriculture for those utilising traditional native breeds of livestock. The move from carcass to cell harvesting could see a shift change away from the genomic and phenotypic selection of high yielding, hybridised breeds of livestock to the utilisation of more traditional livestock who can thrive on low density, low input, and extensive systems. The benefits are three-fold: these low impact systems have a much lower environmental impact, have the potential to be highly profitable, and could potentially contribute to the retention of the genetics of traditional breeds and will safeguard their biodiversity.

Also if the cultured meat industry was developed in such a way as to support it, the combination of traditional agriculture and new technologies will enable a circular economy as the majority of waste products (heat, metabolites) from cultured meat production can be upgraded for use on a farm or sold. There is also the opportunity to establish a true cost accounting structure to realise both the financial and environmental impact of the production of food through cellular agriculture.

8 Challenges

To move from concept to industrial production cultured food needs to overcome a number of challenges be they technical, social, political or ethnical. While the technical challenges of industrial production of cultured milk have mostly been overcame, given the process being used as not new, cultured meat production processes are still fledging and need to be overcame before the sector can move to full industrial production.

All cultured food will need to overcome social, political and ethnical challenges, and the public's acceptance as a mainstream food product if they are to become an industry and potentially replace our current meat and dairy sectors.

8.1 Technical

Within the cultured meat sector there are still a significant number of technical issues and challenges to overcome before they can produce at an industrial scale. These challenges include harvesting cells; availability of culture media at affordable prices and quantities; development of effective culture media that does not use cow blood as a key ingredient; development of bioreactors large enough to produce at an industrial scale; and development of tissue structures to enable production of non-mincemeat products (i.e. steaks).

The bioprocess of producing cultured meat itself can be considered in four parts: the cell expansion; the cell differentiation; the product manufacture; and the waste valorisation.

Before the bioprocess can begin the cell lines need to harvested or created, this can be done either from a live animal or from genetic programmed cells. Creating cell lines is typically done via induction (genetic engineering or chemical), which can program the cells to proliferate indefinitely (Eva et al., 2014). Another is to select spontaneous mutations where the cell expresses immortality and culture the resulting population (ThermoFisher, 2017). These immortalised cells could decrease the dependency on fresh tissue samples and increase the speed of proliferation and differentiation. However, sub-culturing, passaging, misidentification, and continuous evolution are just some of the problems that occur using cell lines (National Institutes of Health, 2007).

The alternative method involves harvesting primary cells found in native tissue, perhaps from a small herd of animals on an intermittent basis, and culturing them. The challenge here is that using primary cells includes isolation of the desired cell type from the harvest tissue, both with regard to homogeneity and cell number; this can be technically challenging, costly and often result in insufficient numbers of cells for any meaningful data to be acquired. Furthermore, inter-sample variability will impact growth behaviour and response to the culture environment. There is still much debate as to the optimal cells to use in terms of animal types, breed, and tissue from which the cells are taken. Muscle stem cells (satellite cells) are the most researched source, but other multipotent cells such a mesenchymal stem cells are being studied due to their higher proliferation capacity (Stern-Straeter, 2014) and ability to be expanded using serum-free media.

As noted by Stephens et al., (2018) the culture media used for both stages of skeletal muscle development is usually supplemented with 10-20 percent of growth media. Foetal calf serum or horse serum is added between the range 0.5-2 percent at the differentiation stage. Chicken embryo extract is also used as an addition to some cultures. Optimisation of the culture media is highly dependent on the cell species origin. In addition, it is common practice to add antibiotic or antibiotics to cells in cultures to prevent infection particularly for long-term cultures.

Foetal calf serum or horse serum contains a wide range of growth factors, hormones, vitamins, amino acids, fatty acids, trace elements and extracellular vesicles required for cell growth (Aswad, Jalabert, & Rome, 2016; Brunner et al., 2010). There have been studies utilising serum-free media through the addition of supplementary proteins (Shiozuka & Kimura, 2000) or new branded media such as AIM-V (Fujita et al., 2010), with promising results. For example, AIM-V has shown increased active tension over serum media during the differentiation stage.

The current use of foetal calf serum or horse serum within the culture media does limit the ability of the cultured meat industry to produce the environmental benefits being touted and replace the current meat industry. Using these serum means that they are heavily dependent on the livestock rearing industry to produce such serums and if production is to increases provide even greater volumes of the serums.

While if commercial media are to be used in a product, a Life Cycle Assessment must be conducted for the purposes of determining its benefits and providing information to customers, although this is complicated because in most cases the proprietary nature of commercial media means the source, extraction method and processing of components remains unknown.

It is possible after all, but somewhat more difficult to grow cells under serum-free conditions or using serum replacements; however, this is itself an area of research that is yet to produce a comparable and affordable alternative (Butler, 2015). Muscle cell culture media are expensive, in fact prohibitive on the large scale, therefore, the manufacture of a sustainable, animal-free, affordable media is a major challenge. The same challenge applies to scaffold manufacture. There are a number of animal and non-animal derived biomaterials that have been utilised in tissue engineering. Myogenic cells prefer to reside in animal-derived materials as would be expected as these materials more closely mimic their natural physiological niche. (Stephens et al., 2018)

Currently successful scaffolds for 3D skeletal muscle formation are all currently animal-derived due to factors such as cell adhesion, fibre alignment and comparability to an in-vivo environment (Bian et al., 2009). The additional consideration is whether the scaffold should be part of the product and therefore edible; or, whether the cells are removed from the scaffold so it can be reused to save material. Cost is also important and it is expected that new scaffolds will continue to be developed for as long as cultured meat products are themselves developed and re-developed.

The current long-term goal for the cultured meat industry is to produce a like-for-like piece of muscle (e.g. steak). While thin 3D cultures can be utilised to form processed meats (burgers, sausages), carcase meats (steaks) would need the optimisation of thicker 3D structures with a nutrient and oxygen supply and waste removal to sustain the inner core of cells. This requires a complex system containing multiple cell types growing in an organised manner, and a structure that will need a replicated blood vessel network. A more simplistic and near-future goal is producing a muscle protein ingredient based on muscle cells alone. Despite these longer term differences, many of the challenges at this point in time are the same for both. (Stephens et al., 2018)

This technical challenge faced by cultured meat processers is a similar one facing researchers working in regenerative medicines and focusing on growing in a lab human organs for transplant. Scientists and researchers working in cultured meat are looking to breakthroughs from the similar regenerative medicine field to help them overcome this technical challenges of growing in a lab thicker more complex tissue structures.

Skeletal muscle tissue engineering aims to mimic regeneration of muscle after trauma and/or embryonic myogenesis. Although cell type and maturation pathways may differ, the end goal is to obtain a terminally differentiated cell capable of proliferating and differentiating into muscle fibres. Typically, tissue engineering for cultured meat focuses on growing myogenic 'muscle' cells (myocytes) alone via the regenerative pathway, as these are the main constituent of meat. However, to achieve muscle tissue that has potential to fully replicate meat, multiple cell types are required (Stephens et al., 2018).

One pathway to solving this challenge is through 3D-printing. Overall 3D-printing seems a promising concept in creating these channelled networks, with examples including cultured leather purveyors Modern Meadow patenting a method and device for 'scalable extrusion of cultured cells for use in forming three-dimensional tissue structures', and Harvard researchers 3D-printing a perfusion network that was able to sustain a culture for six weeks (Kolesky, Homan, Skylar-Scott, & Lewis, 2016).

The last technical challenge is around scaling up bioreactors needed to grow the cells to an industrial viable size. Currently public demonstrated cell expansion have used bioreactors up to 5 litres, though with currently commercially-available technologies there is potential for bioreactors up to 2000 litres in size to be built and used (Schnitzler et al., 2016). To put into context the scale of cultured meat production, in the region of 8 x 1012 cells are required to acquire 1 kg of protein from muscle cells which would need a 'traditional' stirred tank bioreactor in the order of 5000 litres. This is beyond the current commercially-available size and therefore the ability to scale-up (in a few large bioreactors) or the scale-out (in many smaller bioreactors) are key challenges here.

The case for the scale-out approach is achievable but highly labour intensive and costly, so establishing a scaffold and bioreactor conditions that enable differentiation in larger bioreactors is the major challenge to make cultured meat a commodity (Stephens et al., 2018).

8.2 Ethnics and public acceptance

The largest challenge that faces the cultured food sector is not technical but rather social, will the public accept cultured food products as food or will they reject them?

After all due to the absence of the natural pigment myoglobin, the cultured meat looks devoid of its pleasant red colour. And as a matter of fact, it is devoid of the mineral otherwise abundantly present in meat i.e. iron. According to (Datar and Betti 2010), the nutrients present naturally in meat that are not synthesised by the muscle must be provided for example, vitamin B12. Post (2012) has commented that creating or mimicking the natural favour in the in-vitro meat is a gigantic challenge because more than a thousand water soluble and fat derived components bring about the flavour of meat.

In the case of food, the overall sensory appeal overrules the logics. A commodity like food has a psychological and emotional value attached to it implying that the discussions about cultured meat are not always only rational (FST Journal 2013). This means even though people may rationally accept the need for cultured food to reduce the environmental impact of their food, the may not be able to apply the same ration approach to actually eating the products.

This is shown in recent studies which have looked at the willingness of the public to try cultured food products and the role of mainstream media and social media in the debate. Studies by Laestadius (2015) and Laestadiues and Caldwell (2015) of social media and comments on news articles about cultured meat find the perceived unnaturalness of cultured meat can be problem. O'Riordan et al. (2015) notes that social media can be a key site of resistance (there have also been studies of the media reporting itself, with Goodwin and Shoulders (2013) arguing coverage disproportionately draws upon cultured meat proponents, while Hopkins (2015) argues the media over-represents the importance of vegetarian and vegan viewpoints).

An online survey of 643 participants based in the US reported that while two thirds of respondents said they would try cultured meat, only one third would eat it regularly (Wilks & Philips, 2017). While a Dutch study suggested the more participants learnt about cultured meat the more they were willing to support it. Studying the impact of new knowledge on perception was the key focus of another Dutch study, this time using psychological experiments with 506 responses, which found different stimuli information altered individuals' considered opinions of cultured meat, although it did not affect their instinctive positive or negative response (Bekker, Fischer, Tobi, & Van Trijp, 2017).

A recent survey revealed that 80 percent of Americans would not eat lab grown meat (though the younger population is more willing to try it) (CNN 2014). However, in a poll in the UK, 68 percent of the participants voted in favour of cultured meat by saying that they would eat in vitro meat (Guardian 2012).

The other area generating debate is around the ethnics of the cultured food industry. Armaza-Armaza and Armaza-Galdos argue developing cultured meats "would be a moral duty" (2010, p58) while Hopkins and Dacey suggest it "might be our moral obligation" (2008, p579). Supportive but less emphatic is Pluhar (2010) who argues that from both utilitarian and rights-based viewpoints we should support cultured meat, although vegetarianism may be superior moral response. Va der Weele (2010) suggests we should invest in cultured meat to at least see if the benefits can be realised although they is the possibility that the benefits may not be realised.

Cole and Morgan (2013) argue from a critical animal studies perspective that cultured meat continues the existing fetishisation of meat, and due to its expense could result in a non-meat eating elite who operate guilt free at the expense of the less well-off. Weisberg writes with the critical theory of Marcuse and Ellul that "ultimately, looking to biotechnology to solve ethnical crises is fraught with danger and should be avoided" (2015, p52), a position close to Metcalf's (2013) argument that cultured meat is a dangerous example of the decontextualisation and molecularisation of sustainability.

8.3 Political challenges

The last area of challenge is the political and regulatory area, with the challenge here more around what regulations would apply to the cultured food products, given that there is not a set definition for them so far.

Adding to the challenge here is that it is not yet certain what a cultured meat sector may look like (e.g. few large-scale vs many smaller-scale producers), nor what inputs will be required (e.g. animal vs cultured growth media) and what their respective environmental and ethical footprints will be (Stephens et al., 2018).

The key questions to be answered include: who will provide cultured meat (i.e. farmers, agribusiness, bioscientists), and more specifically, who is already enabled to adopt, and potentially profit from, this technology; where will production take place (i.e. Global North/South, on farms/in factories); and, what are the associated social, political, environmental and ethical implications of these developments? Concerns have been raised in public focus groups that cultured meat will provide a new frontier for multinational corporations to accumulate further capital and power over the food system (Driessen & Korthals, 2012), a point also raised by Hocquette (2016) who argues it may further support the domination of Global North economies over those of the South. Conversely, others have envisaged the potential for a shift towards localised and more connected relationships with meat production – for example the 'pig in the backyard' scenario discussed by Van der Weele and Driessen (2013) or ideas of community donor herds that live out their lives serving local areas with their slaughter-free cells. Exploring how cultured meat will become situated within existing socio-political relations regarding the commodification of nature (Birch, Levidow, & Papaioannou, 2010), the different scales of geographies of food production and consumption, and the politics of sustainable and healthy eating (Sexton, 2016), is of critical importance for understanding the ability of cultured meat to realise the promises its proponents currently claim. Importantly, this is a task that must be conducted in the current early stages of the technology and as it develops over the coming years.

Other key issues include one establishing if cultured meat is a product of animal origin. Stephens et al., (2018) believe it likely will be, although challenging this it is worth remembering that (i) when culturing begins the animal cells are a small proportion of material used compared with the culturing media (which may or may not be animal-based), and (ii) cell lines may be considered a processed product.

And two the safety of the product. This requires an awareness of auditing that should be addressed from the outset of animal cell-based cellular agriculture product development as it brings together cell culture and meat science (Stephens et al., 2018). In terms of processing, auditing should include (i) identification of key possible pathogens, and safety measures to inhibit contamination (through a HACCP-based system), (ii) ensuring ageing of meat is greater than 24h to allow for total cell death, (iii) monitoring and quality assurance of cellular functions at each stage (viability, self-renewal, death and differentiation) and pivotal to quality, function and sustainability, assays for cell potency, and testing of genetic stability (Kirouac & Zandstra, 2008), (iv) the managing of metabolic waste by disposal, recycling or upgrading, and (v) production plant hazard and operability study (HAZOP).

The final regulatory issue raised here relates to cellular agriculture from non-livestock species (including humans). A regulatory response will be needed for cellular agriculture products using non-agricultural animals. Categories for consideration include: endangered and protected animals, dangerous animals, companion animals, and importantly, human cellular agriculture (Stephens et al., 2018).

In addition regulatory and political responses will be needed to address two main forms of food safety concerns: (i) attempts to pass cultured meat as conventional livestock meat, and (ii) attempts to pass conventional livestock meat as cultured meat. In the case of combined cultured and conventional livestock meat products there could also be the risk of mislabelling the proportions of meat type.

Appendix A References

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