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Is *In Vitro* Meat An Environmentally, Technologically, Fiscally, And Socially Realistic Agricultural Alternative In The United States?

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A Senior Thesis

Advised by Lucille Johnson and Lizabeth Paravisini-Gebert

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Introduction

Food is one of the great commonalities of humanity. With steadily increasing populations and—in the case of the United States—the steadily increasing appetites of individuals making up those populations, the limited resources the world provides are feeling even more sparse. Traditional forms of making and distributing food products are no longer sufficient ways of feeding the population of the United States. Many people are largely unaware of the limitations of our natural resources. A 2014 NASA study explicitly warned against the "irreversible collapse" of industrial civilization if it continued to operate as it does today (Creighton 2014). Fortunately, a plethora of technological solutions to industrial problems have been proposed and implemented to change our course. Genetically modified organisms (GMOs), for example, have allowed industries to grow much larger batches of stronger, more resilient crops.

Of course, these solutions call into play technochauvinism, the paradox of using technology to solve problems which inherently create new problems requiring new technology to fix. One may ask why we don't simply return to "simpler", "less problematic" ways of food production and consumption. This mindset is seen in the anti-GMO movement, and recent popularity of the Paleo—"caveman"—diet. Statements such as these, while they hold merit on a superficial level, remain completely ignorant to the fact that the way things "were" (i.e., family owned farms, local growers and butchers, etc.) can literally not sustain the massive populations we have created. Furthermore, the amount of land allocated to farming and food production has shrunk, as methods of production have become more efficient and open land is frequently industrialized. The "local farmer" model may work for more rural or less densely populated areas however, people living in urban cities and particularly low-income areas would not have the same level of access. Ipso facto, technological solutions are one of our best bets for realistically changing the way we produce and consume food.

This piece attempts to critically analyze one of these technological solutions: *in vitro* meat. *In vitro* meat is a novel way of producing meat products using stem cell technology. *In vitro* meat products are molecularly the same as traditional meat, but are grown instead of harvested. In the simplest sense, *in vitro* meat production gives consumers “meat without murder”.

Chapter 1 historically contextualizes the modern meat industry. In this chapter, I describe the rise of factory farming and note the “big name” corporations with extreme amounts of power in the meat industry. Chapter 2 describes the way *in vitro* meat technology was established, problems the industry faces today, and current solutions companies are integrating into their research. Chapter 3 takes a more in depth look at the companies, start-ups, and other major role players involved with *in vitro* meat production and research, and the financial part each of these play in it. Chapter 4 discusses the way the public currently perceives *in vitro* meat production and products, and analyzes what types of consumers or demographics correlate with perception. Lastly, Chapter 5 concludes the topics covered in an attempt to answer two overarching questions: can *in vitro* meat products replace traditional meat products and should *in vitro* meat products replace traditional meat products.

My hope is to shed light on one of the up and coming technological solutions to ameliorate the issues we currently face in regards to the meat industry and its practices. Not only do I hope to encourage people to realistically contemplate these solutions, but I want to acknowledge the complexity of integrating them into our existing sociocultural paradigm. Despite these complications, I hope that this piece is one of the first of many in-depth and holistic approaches to next-generation food production.

| I |

The Current State of Agricultural Farming & Its Alternatives

The production and cultivation of meat has played an integral role in the American economy, and meat products have always been important to the American nutritional profile. For a long time small family-owned farms would raise, nurture, and eventually slaughter full grown cattle and chickens to feed themselves and their communities. Industrial agriculture, on a world scale, is a relatively new practice, and has been developed only in the past 100 years (Gyles 2010). In the wake of the rapid economic growth spurred by the Industrial Revolution, larger populations created a demand for more streamlined animal agricultural processes. The Industrial Revolution brought about better medicine and more hygienic living standards, “resulting in the population explosion that would commence at that point and steamroll into the 20th and 21st centuries” (McLamb 2011). Food requirements were no longer met by small family-owned farms. Additionally, technological advancements with vitamins, nutrition, antibiotics, and vaccines created ways to produce more meat while decreasing the risks of diseased products and cattle (Gordon 1996). Agricultural production across the world doubled four times between 1820 and 1975. Likewise, more automated and efficient processing decreased the percent of Americans working in agricultural from 24% in the 1930s to 1.5% in 2002 (Scully 2003). With fewer people working and more production, agriculture has become exponentially more efficient in the past few decades. Alongside streamlining came the rise of factory farming.

Factory farms—also known as concentrated animal feeding operations (CAFOs)—are defined by their total number of animals (>500-head beef cattle, >1,000-head hogs) or the number of (slaughtered) animals sold annually (>500,000 broiler chickens) (Pluhar 2010; Factory Farm Map). Factory farming of beef and dairy cattle and domestic pigs in the United States commenced in 1966 and quickly rose to account for 30% of world meat production in 24 years (Nierenberg 2005). This growth, which continued into the 21st century, was accelerated by three major factors. First, several policies encouraged over-production of corn, soybeans, and other commodity crops. This decreased the price of livestock feed which indirectly subsidized factory farm operations. Second, a lack of environmental rules and enforcement of the policies that were in place allowed factory farms to grow to gargantuan sizes without altering their processing. Finally, meatpacking and poultry corporate companies began to consolidate land and meat product production methods, exerting a significant amount of pressure on producers to become larger and more intensive (Factory Farm Map).

This third point largely defines the United States meat and poultry industries today. Tyson Foods, Inc.—established in 1947 as Tyson Feed & Hatchery, Inc.—is currently one of the largest processors and marketers of meat and poultry products. This corporation and ones like it control every process involved in the "farm to fork" production and marketing of animal products. Tyson now reports an annual revenue of over 24 billion dollars and employs 120,000 people at 300 facilities in 22 countries (Who Controls the Food Supply;*International Directory of Company Histories*; 2018 Top Meat & Poultry Processors).

Alongside Tyson Foods stand JBS USA Holdings Inc., Cargill Meat Solutions Corp., SYSCO Corp., and Smithfield Foods Inc. as powerhouses of the meat and poultry industry (2018 Top Meat & Poultry Processors). These companies, due to their socioeconomic power, are large players in legislative and regulatory political arenas. Via powerful meat trade and lobbying organizations—The American Meat Institute, the National Meat Association, and the National Cattlemen's Beef Association—these corporations have a significant amount of influence on policies, rules, and regulations affecting or with the potential to affect their industry. This influence has created a notoriously close and comfortable relationship between these major meat institutions and high-level U.S. Department of Agriculture (USDA) employees. In particular, powerful meat trade and lobbying organizations have a historically relevant relationship with the Food Safety and Inspection Service (FSIS). Through these connections, the meat industry has been able to delay and inhibit new food-safety and environmental regulations. These provisions frequently come at a cost to the meat industry which they willingly pay as they invest in strategically chosen government employees who have and will act in their interests (Johnson).

The accumulation of political puppets financially incentivized by the meat industry has contributed to the extreme lack of environmental accountability or sustainability that characterizes these corporations. Factory farming and meat production have numerous byproducts that contribute to greenhouse gas emissions and the subsequent climate change they influence. Methane gas (CH_4), produced from cattle manure, is one of the most prominent natural pollutants. The farm animal sector accounts for 37% of CH_4 emissions annually. Keeping cows and pigs in more confined spaces in larger facilities and liquid manure management systems—manure lagoons—have resulted in a 150% increase in CH_4 concentrations since 1750 (Greenhouse Gas Emissions; Steinfeld et al. 2006). Additionally, fueling factory farms, production of high-energy feed, processing and packaging of meat products, deforestation, feed crop cultivation, and desertification account for 9% of human-induced emissions of carbon dioxide (CO_2), a cause of climate change. Growing feed crops and other farm animal production also account for 65% of nitrous oxide (N_2O) emissions (Greenhouse Gas Emissions). Aside from emissions, factory farms also consume extremely high levels of fossil fuels, water, and topsoil. Furthermore, farming live animals requires a significant amount of grain-based crops as sources of feed (Horrigan et al. 2002). Animals fed plant proteins that humans could also eat not only take away this resource, but yield large net protein losses: 1 pound of beef requires 7 pounds of corn, 1 pound of pork requires 6.5 pounds of corn, and 1 pound of chicken requires 2.8 pounds of corn (Pluhar 2010; Lavelle and Garber 2008).

Beyond the lack of environmental sustainability, relatively recent events have begun to expose the meat industry's unethical treatment of their animals. As efficiency, output, and profits became the sole focuses of the meat and poultry industry, animal health and welfare became less of a priority. Major sources of CAFO-induced animal suffering today include extreme overcrowding, physical alterations such as teeth-clipping or tail-docking for convenience, indoor confinement with poor air quality, extremely high rates of breeding, neglect of sick or suffering animals, and rough or abusive handling (Farm Animal Welfare). Paul Shapiro, a former vice president of farm animal protection at the Humane Society, claimed in an interview that "animal abuse is the norm in the meat industry". Investigations launched by Mercy for Animals, PETA, and the Humane Society of the United States regularly uncover instances of animal abuse and mistreatment (Velez-Mitchell 2014). Unsanitary and cramped living conditions lend themselves to antibiotic overuse to keep the animals as healthy as possible in unhygienic conditions, which has been shown to contribute to human antibiotic resistance. Human antibiotic resistance is currently responsible for 23,000 deaths/year in the United States. Industrial slaughterhouses, again for the sake of efficiency, also kill animals at an extremely rapid rates and often experience tragic mistakes which include animals not being rendered unconscious before being killed or being skinned alive (Factory Farms Abuse Animals).

Mistreatment of low level workers in the meat and poultry industry is also common. Slaughterhouse and meat and poultry processing workers are often exposed to unsanitary, hazardous, and abusive working conditions. Slaughterhouses and meat-processing plants have been categorized as some of the most dangerous factory workplaces in America (Lowe 2017). Workers, mostly immigrants and refugees, suffer high rates of injuries and deaths. The negotiated government fines for these tragic accidents are, on average, $10,993 compared to the average initial fine of $19,340. Several scholars have claimed that this significant decrease is a result of the meat industry's powerful connections serving them in the legal sector as well in addition to the political one. Furthermore, investigators have found a significant number of serious accidents, some including fatalities, at the top four U.S. meat companies that went entirely unreported (Hunzinger).

Many of these conditions are largely a result of the extremely high (and increasing levels of) meat and poultry consumer demand and consumption in the United States. In 2017 the United States consumed a total of over 12 million tons of beef and veal, 9 million tons of pork, and 18 million tons of poultry (OECD 2018). On average, Americans eat four times as much beef as the rest of the world (Waite 2018). The average American was projected to eat 222.2 pounds of red meat and poultry in 2018, beating out the previous record of 221.9 pounds set in 2014 (Durisin & Singh 2018). These meat-eating habits far surpass what is required to meet humans' nutritional needs (Chemnitz & Sharma 2014). There has, however, been a significant shift in United States meat consumption from beef towards chicken since 1970 (Waite 2018).

It is important to understand how trends in meat and poultry consumption apply to various demographic spectra. On average, men consume absolutely more meat, poultry, and fish than women. Additionally, the average individual 20-49 years of age consumes the more meat relative to other age groups. White Americans were shown to eat less meat than Hispanic or black Americans (weighted means of 124g, 128.6g, and 140.2g respectively) (Carrie et al. 2011).

While ethnic and cultural factors are likely part of these observed differences, one of the most prominent determining factors of the amount of meat an American consumes is their financial standing. The streamlined efficiency of CAFOs has decreased the price of many processed meats, whether they be in supermarkets or restaurants (most prominently in fast food restaurants). Meat can be frozen for a long period of time, while fresh fruits, vegetables, and grains are more difficult—and more costly—to store and transport (Rampell 2010). Furthermore, the United States government directly subsidizes agricultural meat. Data from 2016 shows that the US government spends $38 billion every year to subsidize the meat and dairy industries. This money directly reduces the price of these products and allows these prices to remain low. In comparison, the same dataset noted that the US government spends only $17 million every year to subsidize the fruits and vegetable industries (0.04% of what it spends subsidizing meat and dairy). Government subsidization allows meat to be more accessible to people across the nation, and increases the meat products' share of Americans' daily consumption (Insiders 2016). While the price of meats has remained constant (with a slight decrease) since 1978, the prices of fresh fruits and vegetables have skyrocketed (Leonhardt 2009). For this reason, meat products may be the only way many low-income Americans acquire nutrient-dense foods.

Regardless of socioeconomic status, however, consumers as a whole are eating more meat and poultry than ever. The way in which consumers perceive the meat industry, however, has changed in a variety of ways. These changes have been largely driven by a growing sense of the ethical and environmental implications of the current practices of meat corporations. This is influenced commercial animal production being increasingly depicted by the media as controlled by corporate interest and being motivated by profit over traditional animal care values (Fraser). Over the past few decades, journalists and broadcasters have jumped at the opportunity to cover instances of “food scandals” (Meat and the Media). For example, in 2012 ABC correspondent Jim Avila reported on the addition of “pink slime”—pre-butchered lean bits of cow derived from muscle and connective tissue—to 70% of ground beef in supermarkets. This news story caused sudden public awareness and outrage and, while the “pink slime” was common and not unsafe to eat, directly caused Beef Products, Inc. (the target of the story) to close three plants and lay off more than 700 workers (Siegel 2017). Stories like this, particularly when portrayed for “shock value”, are not necessarily common but are a part of a trend in increasing consumer consciousness when it comes to meat and poultry products.

United States consumers across all demographics have demonstrated a willingness to seek out and pay more for more ethically obtained and healthier animal products in supermarkets and restaurants (Spain et al. 2018; Erian & Phillips 2017). Millennials, more than any preceding generation, are generally interested in animal welfare, organic food, and having a more complete understanding of the farm-to-fork process. Younger and more highly educated consumers are more regularly seeking out new sources of protein and emphasizing traceability and sourcing when purchasing new proteins (Corish 2017). The cumulation of environmentally and ethically unstable processing and the rise of the conscious consumer has created a need to reform the way Americans make and consume meat and poultry products. The fact that overall meat consumption remains at an all time high implies that the“conscious consumer” is more focused on where they get their products from, instead of avoiding those products all together. Meat and poultry processing corporations that successfully meet these need are able to adapt are become preferred, while those that do not are under threat of rejection in favor of other options. Corporations and consumers alike are scrambling to propose new ways to develop healthier, sustainable, and more ethical ways to deal with the meat industry.

The most standard reforms to the meat and poultry industry include several humane and sustainable farming initiatives. These initiatives are often propagated by meat corporations themselves in response to consumer demand for more ethical processing. “Free-range”, “organic” and “humane” are words associated with more desirable products, and they are becoming increasingly common as a label for meat products in supermarkets and restaurants. These words create a significant amount of buzz and temporarily satisfy the consumer’s need to feel as though their food is acquired in a more humane manner while still eating what they want (Bohanec 2014). Through these labels and more extensive educational processes consumers are supporting humanely obtained meat and poultry products so that they can access healthier and “happier” food. As many consumers are not willing to become vegetarians, purchasing and eating humanely farmed meat is a more realistic step in the right direction in terms of farm animal welfare.

Humane farming prospects include shifting meat and poultry product processing from large corporate industries to smaller family farms more reminiscent of pre-corporate agriculture.

Smaller farms have a greater tendency to practice sustainable agriculture and humane treatment of the animals, relieving both ecological and ethical strain found in the meat industry. Furthermore, animals kept in less stressful conditions do not require the same amount of antibiotics as do those raised in crowded and unsanitary factory farms. This would contribute to a decrease in meat-based effects on human antibiotic resistance as well as health issues for the animals themselves (Pluhar 2010).

While humane farming seems like one of the easier ways to still produce meat products, there are several problems with this alternative. The available pasture on earth cannot humanely sustain the 1.3 billion cattle present in factory farms. A shift to smaller family-owned farming methods would also require a significant decrease in the amount of meat consumption in the United States. It would also likely cause increases in the price and inaccessibility of meat and poultry products which could be nutritionally devastating for low-income or impoverished Americans (Bittman 2008). Additionally, while humane farming methods would certainly relieve some stressors and unethical practices, farm animals could still face grisly and frightening deaths as slaughtering mechanisms often remain the same on small farms as those on factory farms (Pluhar 2010; Gruzalski 2004; Pollan 2006). Furthermore, claims of “humane” meat and poultry products tend to mislead consumers into thinking their food is entirely “cruelty free” (Bohanec 2014). In this way, human farming initiatives harbor the potential to mislead consumers and decrease their active role in pushing for more ethical and environmentally sustainable production methods.

Humane farming, despite its apparent problems, would be a marginally more ethical and environmentally sustainable alternative to factory farming. Many people, however, don’t feel as though a shift from CAFOs to humane farms would be significant on a large and more long term scale. Online communities and larger organizations such as People for the Ethical Treatment of Animals (PETA) remain adamant that the only effective environmental, ethical, and healthy solution to the problems created by CAFOs is wide-scale vegetarianism or veganism. Vegetarianism would not only eliminate ethical problems in the meat and poultry industry, but would decrease the environmental expenditures associated with these processes (Pluhar 2010). While pesticide- and herbicide-treated produce carries its own risks, meat retains toxin concentrations that far exceed these dangers. Furthermore, despite the environmental implications of mass-producing any food products, largely decreasing meat production would allow more efficiently concentrated environmentally sound efforts of production. Vegetarianism has also been reported to have significant health advantages in regards to preventing and ameliorating diseases when compared to the traditional, meat-heavy American diet (American Dietetic Association 2003).

The first thing to consider when analyzing the feasibility of a shift to an all (or mostly) vegetarian American diet is how willing people would be to give up their meat-based diet entirely. Estimates indicate vegetarians make up anywhere from 2% to 7% of the United States population. Significantly, many of those who self-identify as vegetarian do not wholly abstain from consuming animal flesh whether it be poultry or fish (S.K. 2005;How many vegetarians… 2006; Akers 2008). The overall rise in meat consumption in America is evidence that despite the somewhat increasing popularity of vegetarianism, it has little impact on the demand for meat products.

Further increasing the rate of vegetarianism is highly unlikely when taking into account the cultural significance of meat in the United States. Meat has been historically integral to the American diet and has acted as a strong indicator of socioeconomic status for years (Charles 2012). Around the world, "[E]ating large quantities of meat has become a cultural imperative… having become a sign of affluence and modernity and a 'right' of consumer choice" (Dagevos & Voordouw 2013). Meat consumption is also strongly associated with masculinity, something American culture promotes to a harmful capacity. A study conducted by Ruby & Heine (2011) found that groups of people with both vegetarian and omnivorous diets rated vegetarian targets are less masculine than omnivorous ones. Several feminist scholars have made connections between "vegetarian feminism" and an "animal-eating patrichy". Carol Adams, in her book *The Sexualization of Meat* (2015) asserts that "the meanings attached to meat eating include meanings clustered around virility" (xxvi). Living in a patriarchal system that aggressively values hypermasculinity, makes the more docile, feminist choice of abstaining from meat consumption far less desirable and socially acceptable.

This has likely influenced recent cultural trends that have pushed a culture that shames and demonizes vegetarians and vegans as norm-challenging others. One study even found that vegans are outwardly viewed more negatively than atheists, immigrants, homosexuals, and asexuals (MacInnis & Hodson 2017). Despite an increasing awareness of the ethical, environmental, and health-related issues associated with meat and meat production, these sociocultural perceptions of meat remain strong, and are a huge barrier to achieving widespread vegetarianism. Overcoming this barrier would require extensive outreach that address misconceptions about vegetarianism not only directly, but on a more indirect, social level.

These two alternatives—humane farming and wide-scale vegetarianism—are still being lobbied for by various companies and people. Granted, each "solution" comes with its own shortcomings; however, this chapter has demonstrated that a change is necessary. The coming chapters define and discuss *in vitro* meat and explain how it could be applied to solve problems industrial animal agriculture has caused across many sectors. While *in vitro* meat, as will be explored, is an imperfect alternative itself, there is evidence to support the argument that it is the *most* complete and viable alternative to the traditional meat processing and products.

| II |

The Technology Behind Clean Meat Processing

The production process behind *in vitro* meat is extremely new, which makes it rather difficult to generalize the technology and steps behind it. Much like all food processing, each step within processing has multiple ways in which its primary goal can be achieved. There is a divide, however, between two overarching techniques that differ significantly from one another: a self-organizing technique and a scaffold-based technique. These two techniques show differences in their starting materials, processes, and final products. Both have been dubbed methods of producing *in vitro* meat due to their ability to grow meat in a lab culture and selectively manipulate its composition (Sharma et al. 2015; Edelman et al. 2005).

The self-organizing technique is the arguably less technologically advanced method of creating *in vitro* meat products. The roots of this process date back surprisingly far. One of the first predictions of the use of *ex vivo* techniques to develop meat for human consumption came from Winston Churchill in the 1920s. In 1912 Alexis Carrel, a French surgeon and biologist, was able to keep chick heart muscle alive and beating in a petri dish in the presence of nutrients (Bhat & Bhat 2011). Nearly a century later there was a tremendous leap from maintaining living tissue *in vitro* to growing living tissue *in vitro* which laid the foundation for *in vitro* meat production.

Benjaminson et al. (2002) sought to use food technology to create more highly suitable living conditions for long-term mission Space vehicle crews. These researchers used several experimental treatments to determine the efficacy of in vitro muscle protein production systems (MPPS) for the fabrication of surrogate muscle protein constructs from skeletal muscle mass of common gold fish. Benjaminson et al. (2002) were able to produce an edible product which "resembled fresh fish fillets". These experimental trials were essential in determining the most effective media in which to proliferate tissue *in vitro*. Over seven days Benjaminson et al. (2002) showed a growth rate of 13.8% in fetal bovine serum, 7.1% in fishmeal extract, 4.8% in shiitake extract, and 15.6% in maitake extract.

The techniques used by Benjaminson et al. (2002) are the basis of the methods used to produce self-organizing *in vitro* meat. These processes use an explant from the muscle cells of a donor animal which is then proliferated in a nutrient medium. On the upside, the tissues formed using this technique have the ability to closely resemble traditional meat. This is due to the presence of muscle, fat, and other cells in familiar proportions in the product embodying structured, three dimensional meat. Therefore, this process requires far less manual tissue engineering that its alternative. On the other hand, the self-organizing technique falls short in several areas (Sharma et al. 2015). Lack of blood circulation in the grown tissues limits their ability to remain viable for an extended period of time (Dennis & Kosnik 2000). This, combined with the limited proliferation potential, requires new biopsies from donor animals on a regular basis (Sharma et al. 2015).

The second way of producing *in vitro* meat is the scaffold-based technique. This process consists of suitable stem cells being proliferated while attached to a scaffold or carrier, and perfused with a culture medium in a bioreactor (Sharma et al. 2015). Artists—not scientists—Oron Catts and Ionat Zurr (2002) were two of the first to demonstrate the ability to grow self-described "tissue sculptures" or "semi-living objects" by culturing cells on artificial scaffolds. Their research was done as part of the Tissue Culture & Art (TC&A) Project, and their published writing emphasizes its multidisciplinary yet heavily artistic nature. Catts & Zurr (2002) spoke mainly to the diverse application of the TC&A Project from custom-made replacement organs to entire "semi-living objects". Prior to their 2002 publication the researchers succeeded in growing epithelial tissue from rabbits, rats, and mice, connective tissue from mice, rats, and pigs, muscle tissue from rats, sheep and goldfish, bone and cartilage tissues from pigs, rats, and sheep, mesenchymal cells—bone-marrow stem cells—from pigs, and neurons from goldfish (Catts & Zurr 2002).

In a beautifully artistic and scientific project, Catts & Zurr (2002) "gave birth" to seven Guatemalan worry dolls in an "artificial womb". These dolls were representative of seven culturally-relevant worries: Absolute Truths and people who think they hold them, Biotechnology and the forces that drive it, Capitalism & Corporations, Demagogy and possible Destruction, Eugenics and the people who think that they are superior enough to practice it, the fear of Fear itself, Genes as present in the semi-living dolls themselves, and the fear of Hope. The dolls were featured as an art installation at the Ars Electronica Festival 2000 in Linz, Austria and onlookers were able to view time-lapsed movies of the tissue growth and see the dolls via microscope. Catts & Zurr's project beautifully exemplifies the necessity of both art and science in the proliferation and construction of *in vitro* meat (Science Gallery Dublin 2011). While the artists were perhaps entirely unaware of the application of their technology to edible meat products, their work was significant in understanding ways in which tissue growth could be manipulated for a particular purpose. Today, scientists have derived scaffolding techniques for creating meat from cell culture from Catts & Zurr's artistic endeavours.

Scaffold-based techniques of *in vitro* meat production provide the benefit of controlled, three dimensional tissue engineering. As van Eelen notes, this is exceedingly positive in regards to eliminating potentially unwanted aspects of traditional meat such as gristle and fat. Alternatively, if one were to desire more fat in the meat they were consuming they would be able to get it simply by altering their starting materials. Having control over the entire composition of a meat product gives tissue engineers the potential to create niche products. For example, this technique could result in a meat product more suitable for the elderly or those who struggle with eating tougher foods (Van Eelen et al. 1999). Scaffold-based techniques are generally considered more suitable for generating processed ground meat products. Production of highly structured meats such as marbled steaks, while possible, would be extremely difficult and expensive to engineer with this process (Edelman et al. 2005).

Despite these setbacks, most modern-day research involving *in vitro* meat production focuses on using the scaffold-based technique as it allows for more control in the laboratory. This technique can utilize either embryonic myoblasts ("juvenile" muscle cells) or adult skeletal muscle satellite cells as its initial sample. To mimic traditional meat which is made of muscle, fat, and protein, scaffold-based *in vitro* meat is mainly composed of skeletal muscle. This is achieved through the proliferation, differentiation, and fusion of the aforementioned cell types (Langelaan et al. 2010). Post (2012) and Williams (2012) have researched several variants of these initial cells and acknowledge the positive and negative ways in which their use affects *in vitro* meat production.

Embryonic cells are pluripotent, meaning they have the ability to differentiate in a multitude of ways. These cells tend to be favored in the production of *in vitro* meat as they allow researchers to grow myocytes, adipocytes, and blood vessels—all of which are present in traditional meat. Myoblasts are a subset of embryonic cells which are most frequently used in *in vitro* meat production. These cells differentiate into muscle cells, which fuse together to create a preliminary two dimensional structure and eventually the three dimensional shape of a muscle. Significantly, scaffold-based techniques do not require different myoblasts to produce different "cuts" of meat (i.e., thigh myoblasts to produce thigh meat) as the meat's characteristic texture and taste comes from its use and structure rather than the myoblasts themselves (Williams 2012). These cells are accessible via sampling animal tissue, and through proliferation and tissue engineering a single, microscopic tissue sample from a cow can generate 80,000 quarter-pound beef patties (Schaefer 2018).

Since the tissue sample taken from the animal is so small, *in vitro* meat producers must find a way to proliferate the sample cells *ex vivo* to create exponentially larger products. Embryonic stem cells naturally proliferate; however, several ways of accelerating and sustaining proliferation without extensive differentiation among the cells have been developed. Leukaemia inhibitory factor (LIF) is a cytokine (i.e., growth factor) that has been shown to significantly stimulate growth of immature muscle cells and inhibit cell differentiation (Austin & Burgess 1991). In order to expose cells to enough LIF to reap these benefits, the compound must be put into a blood serum, which requires the slaughter of animals to be created. This is rather counterintuitive when taking into account that one of the main driving factors behind *in vitro* meat production are the ecological and ethical benefit that come with not having to slaughter animals. LIF, therefore, is not the most ideal solution to proliferate cells in the making of *in vitro* meat (Austin & Burgess 1991; Williams 2012).

Alternatively, nanog is a gene active in embryonic stem cells prior to their differentiation. This gene has shown the ability to maintain pluripotency in cells while they continue to proliferate (Chambers et al. 2003). Nanog is present in all cells; however, when a cell begins to differentiate (for example, becomes a muscle cell) the gene becomes inactive. In the production of *in vitro* meat, a "batch" of embryonic stem cells could be genetically modified to keep their nanog genes activated for an extended period of time. This genetic modification would ensure the production of as many cells as desired from a single tissue sample if given sufficient nutrition. This method of proliferation is both ecologically and ethically beneficial as it takes advantage of a naturally occurring attribute in the cells. Furthermore, the method is financially viable as the genetic modification itself would be a rare and inexpensive necessity (Williams 2012).

The media in which these cells—genetically modified or not—proliferate is essential to their rate of growth and survival (Benjaminson et al. 2002). Nutrient-rich media allows these cells to survive *in vitro* for an extended period of time. Fetal calf serum (FCS) is the standard culture for nourishing cells *in vitro*. Acquiring FCS, however, requires the slaughter of pregnant cows which, like LIF, negates many of the ethical arguments for *in vitro* meat production. Use of FCS to nourish cells during proliferation would require the breeding, maintaining, and slaughtering of cows which would likely propagate the maltreatment of animals and workers in the meat industry (Williams 2012). It is possible to argue that FCS could be produced in an ethically conscious setting that protects the rights of its workers and humanely treats and slaughters the animals involved. However, if *in vitro* meat is to be produced in quantities competitive with agricultural meat, the risk for exploitation of employees and harm to animals is high. Furthermore, the production of FCS would also eliminate some of the environmental appeal of *in vitro* meat, and limit its marketability. Additionally, FCS as a compound is ill-defined and therefore an ambiguous factor in cell culture. FCS production leaves room for significant variability, which could be a potential source of microbial contaminants such as fungi, bacteria, mycoplasma, viruses, or prions (Brunner et al. 2010). If *in vitro* meat companies are unsure of the exact compounds they are utilizing in production, the resulting product may have unknown, unstandardized, and potentially unsafe properties. Particularly in mass production—as would be necessary for *in vitro* meat to compete with agricultural meat—variability is extremely undesirable and can be a source of many problems.

Alternatives to FCS are a necessity when assessing the potential future of *in vitro* meat. Importantly, each type of stem cell requires a specific sera to proliferate in. While media for several different cells have been found, many of them still contain animal derived or related substances (Williams 2012). Serum in cell culture media provide growth factors and hormones, proteins, amino acids, vitamins, fatty acids and lipids (Brunner et al. 2010; WIlliams 2012). Finding a non-animal related substance that checks each and every one of these boxes is one of the more predominant problems surrounding *in vitro* meat production. Protein fractions from plant extracts—vegetal serum—are one of the more promising emerging alternatives (Pazos et al. 2004; van der Valk et al. 2004). While it is difficult to find a continuously available and reliable commercial supply of vegetal serum, an increasing number of vendors and companies are entering the field (Brunner et al. 2010). If support and funding for *in vitro* meat is maintained in the coming years, it is probable that demand for products such as vegetal serum will encourage the development of more financially affordable and readily accessible commercial supplies of these sources of nutrition.

Unlike self-organizing techniques of producing *in vitro* meat, scaffold-based techniques require manual tissue engineering to create a product with the same structure and texture of many traditional meats. As seen in Catts & Zurr's (2002) use of the Guatemalan worry dolls, there are a variety of forms scaffolds can take. However, there are a few requirements which these scaffolds must meet in order to function properly. The main purpose of the scaffold is to mimic healthy, undamaged muscle (Engler et al. 2005). A scaffold should be flexible enough that muscles are able to contract and stretch in order to develop a product that is able to replicate the characteristic texture of meat. Additionally, the scaffold itself should be able to separate from the finished product easily or be entirely edible. Furthermore, since muscle cells need to be anchored to grow, the scaffold must have a large enough surface area to promote attachment (Williams 2012). Two distinct scaffolds have been proposed for this technique (Boland et al. 2003).

Willem van Eelen suggested the use of a collagen meshwork. Additionally, van Eelen suggested that the culture media should be refreshed from time to time (Sharma et al. 2015). Van Eelen filed for a patent in 1997 for his production method which describes a collagen or synthetic matrix in which sustain *in vitro* growth. These matrices would produce a number of grown monolayers which would be compacted with one another to create a three dimensional structure. Van Eelen noted the benefits of generating a meat product both free of fat, bone, tendon, gristle, growth hormones, as well as eliminating "animal suffering or concomitant ethical, religious, economical, and environmental problems" (Van Eelen et al. 1999). However, many of the modern iterations of collagen meshwork—also known as the "sponge"—are still derived from cow products (Datar & Betti 2010). Therefore, this scaffold is somewhat counterproductive concerning the ethical driving forces behind *in vitro* meat. Furthermore, cells grown within a sponge or collagen meshwork are relatively more difficult to retrieve once they have diffused into the scaffold (Williams 2012).

The second scaffold option consists of small edible beads or spheres. Vladimir Mironov is the director of the Shared Tissue Engineering Laboratory at the Medical University of South Carolina in Charleston. Mironov submitted a detailed project proposal to NASA in the early 2000s describing how to grow cells on protein spheres suspended in growth medium (AFP 2011). Mironov and his partner Nicholas Genovese were funded by NASA for a number of years, and received a three-year grant from the animal rights activists People of Ethical Treatment of Animals (PETA) in 2011. Mironov's technique utilizes myoblasts as starting cells. The myoblasts are then mixed with tiny spheres of collagen protein and kept in suspension with the help of a microgravity bioreactor (Wolfson 2002). This results in "Porous edible chitosan spheres seeded with myoblasts from edible animals" (AFP 2011).

Minorov's beads eliminate the need for animal products in creation of the scaffold and the need to separate the final product, however, they fail to solve an additional problem. This scaffold proves difficult to stretch, particularly when upscaled industrially. One of the proposed solutions to this setback is the use of spheres that expand and contract as a response to environmental factors such as pH (Lee 2003). While this solution has potential, currently *in vitro* meat processes are almost entirely oriented around unstructured meat that can be used in minced and patty-based foods. These products can also be enhanced and made to be more similar to traditional meat since desired proportions of fat cells (adipocytes) can be grown in a separate culture and added to the meat. In order to expand outside of the realm of unstructured meat, significant changes regarding the structure of *in vitro* meat need occur. When three dimensional structures are engineered, many of the cells' access to their nutrient supply is limited creating an unsustainable product. In order for cells to survive the structure needs to have an oxygen carrier or vascular system that can diffuse between the cells. For this reason, significant advances in blood vessel synthesis is absolutely necessary to generate structured *in vitro* meat. Vasculogenesis is the "production of blood vessels without the presence of other vessels already there" (Williams 2012). This field, oriented around angioblasts, could prove to be a major step towards solving structural and textural problems associated with the lack of blood vessels in *in vitro* meat. However, vasculogenesis is still in its infancy, and would require a substantial amount of additional research before being put into practice (Williams 2012).

When growing tissue *in vitro*, the typical functions of blood must be fulfilled. *In vivo*, blood is able to supply muscles with glucose and oxygen while also taking away waste products. As aforementioned, various tissue cultures are able to supply nutrition and therefore negate the need for blood flow in providing glucose. Removal of waste product is relatively easy to replicate *in vitro* as it can occur via run off or diffusion into the air. The most difficult function to replicate is the ability to deliver oxygen. This cannot be performed by the culture medium itself. Researchers therefore have developed the use of either artificially produced haemoglobin or perfluorochemicals (PFCs) to provide the cells with oxygen (Williams 2012). PFCs are easy to produce, however, their carbon-fluorine bond is extremely strong making them difficult to break down. The presence of these chemicals is a major deterrent in the production of *in vitro* meat as they have been shown to be damaging to animals' organs (Lee 2003). Artificial hemoglobins, however, are harmless and have been successfully produced from genetically modified plants and microbes (Datar & Betti 2010). These production methods have not been performed on an industrial scale (Williams 2012).

Use of artificial hemoglobin also offers a way to keep *in vitro* meat factories free from pathogens. Since these hemoglobins would provide the cells with oxygen, the cells could be kept in an argon atmosphere. Therefore any pathogens—which need to get their oxygen from the air—would be killed and unable to infect the product. While this does not account for any pathogens living in the culture itself, testing of the meat post-production would likely be able to find any infected product. Use of an argon atmosphere decreases the risk of infection without the use of antibiotics. Since increasing antibiotic resistance through consumption of agricultural meat is one of the arguments in favor of *in vitro* meat production, it's important to retain this appeal. Argon atmospheres are desirable because they eliminate the need for antibiotics and the subsequent risk of developing antibiotic resistance upon final product consumption. Overall, however, *in vitro* meat factories would require exceedingly high standard hygiene levels (Williams 2012).

As has become obvious from the description of *in vitro* meat processing, several areas need be further researched, developed, and improved upon in order to produce commercially viable products. On the positive end, however, most every setback that has been described also has known potential solutions. Currently, several *in vitro* products are being produced. This is occurring on small scale levels, but are giving a tremendous amount of insight into how to upscale the processing.

| III |

Major Role Players and Current Initiatives

Scientific potential can only be realized if sufficient interest is expressed from both large and small role players. In the case of *in vitro* meat, these role players are creating, selling, researching, and supporting *in vitro* meat products despite the adversity in the technology involved. This chapter intends to identify and describe major companies that are currently working or have recently worked towards creating consumer *in vitro* meat products. Additionally, this chapter will note individuals and/or groups that are affiliated with these companies and support them economically.

The first time physical *in vitro* meat was put before the eyes of the public was in early August of 2013. During a scientific press conference in London, Mark Post debuted his *in vitro* burger. This burger was constructed using the scaffold-based technique. The entirety of the €250,000 (nearly U.S. $286,000) development cost was paid for in full by Google co-founder Sergey Brin (Jha 2013a). Brin, one of the wealthiest men in the world, said that his investment was for animal welfare reasons stating, "When you see how these cows are treated, it's certainly something I'm not comfortable with" (Jha 2013b). Brin also spoke to the extreme nature of the project claiming "If what you're doing is not seen by some people as science fiction, it's probably not transformative enough" (Jha 2013b). The money was used to grow 20,000 muscle fibers from cow stem cells at Maastricht University over three months. The fibers grown were pressed together to form a single burger. Chef Richard McGeown cooked and served the burger after it was colored with beetroot juice and shot through with saffron. Author Josh Schonwald from the Chicago-based Taste of Tomorrow and Hanni Rützler of Future Food Studio in Australia both tasted the ground-breaking patty on the live television. While both tasters were pleasantly surprised with the texture and taste of the burger their critiques included the lack of juiciness or seasoning (Jha 2013a). Significantly, Post's burger was grown with the use of fetal bovine serum. However, this stunt influenced New Harvest—a cellular agricultural company—to give $50,000 to Post's lab for further research into an entirely animal-free method of producing *in vitro* meat (Meat the Future).

While Post and other researchers remain essential in improving upon *in vitro* meat production, the creation of commercially-oriented companies was a huge step in actualizing dreams of *in vitro* meat products reaching the average consumer. San Francisco startup Memphis Meats was founded in 2016. The company—self-proclaimed the "future of meat"—entirely focuses on experimenting with *in vitro* meat products (Gelman 2016). Within its first year Memphis Meats gained the support of an extremely influential group of investors, accumulating a total of $17 million dollars (Memphis Meats 2017). The "Series A fundraising round" was led by the major venture capital firm, Draper Fisher Jurvetson (DFJ) (Troitino 2017). DFJ is a huge role player in the science and technology spheres and made over 800 investments of a cumulative value of billions of dollars (DFJ Investments). Other companies that have received investments from DFJ include Twitter, Tesla, and Skype; however, its involvement with Memphis Meats "marks the first public commitment to the clean meat movement by top venture investors or meat industry leaders" (Memphis Meats 2017; Troitino 2017).

Alongside DFJ were food industry giants such as Cargill Inc.—ranked number 15 on the Fortune 500 in revenues at the time of the investment—and Kimbal Musk (Troitino 2017).

Significantly, Tyson Food Ventures also invested in Memphis Meats (Cosgrove 2018). One would think Tyson Food Ventures and other companies within the meat industry wouldn't want to invest in a potential competitor. Corporations, however, are increasingly aware of niche marketing opportunities that traditional meat can't access. Instead of feeling threatened by a novel meat production strategy, corporations like Tyson Food Ventures are ensuring that they have a hand in the research, development, and profits associated with *in vitro* meat (Our Meatless Future 2019).

Powerful individuals such as Bill Gates and Richard Branson also contributed in this first round of investment. The money allowed Memphis Meats to accelerate its work in creating *in vitro* meat at a more commercial level (Troitino 2017). This financial support—also accumulated in additional fundraising rounds—helped Memphis Meats reach several historically significant steps including the first "clean meatball" in February 2016 and the first "clean poultry" in March 2017 (Memphis Meats 2017). Furthermore, the company was able to significantly decrease the cost per pound of lab grown meat in the past five years (from $300,000 to $2,400 per pound) (Nelson 2018). While this number remains unrealistically high for the average consumer—primarily due to the expense of the media in which the cells are cultured—Memphis Meats has clearly stated their goal to reduce that cost to less than $5/pound (Stone 2018). The company has projected their premiere of cultured meat to occur in 2021 (Lamb 2018a).

Finless Foods is another company looking to make *in vitro* meat a consumer product. True to its name, it is focused entirely on creating *in vitro* fish and seafood. The company cites the commercial exploitation of fish species claiming, "53 percent of the world's fisheries are fully exploited and 25 percent are overexploited, depleted, or recovering from depletion" (Finless

Foods). Finless Foods currently is working to produce bluefin tuna in order to decrease the strain of wild fishing on the species. Finless Foods has stated their goal as eradicating the need for commercial fishing (Akhtar 2018). In June of 2018 CEO Michael Selden announced that the company was able to close a $3.5 million seed round of fundraising. This funding was led by Draper Associates, an early stage venture capital firm that has invested in companies such as Tesla, Skype, Twitch, and Hotmail (Draper Associates). Selden also emphasized Finless Foods' partnership with Hatch. Hatch is a Norwegian company that is credited with creating the world's first aquaculture accelerator. These partnerships have allowed Finless Foods to dramatically lower costs, secure cellular material, and take other steps that will push them into "rapid commercialization within years, not decades" (Selden 2018; Lamb 2018b). The company has announced hopes to get their cultured bluefin tuna on the market in 2019 (Lamb 2018a).

Formerly known as Hampton Creek, JUST—a company known for creating plant-based products that mimic animal-based ones—announced in June of 2017 that they were entering the *in vitro* product race. JUST announced they were seeking to bring *in vitro* chicken to market by 2018. This task, if it were fulfilled, would have made it the first company to have an *in vitro* meat product available to the public (Lamb 2018a). Within the last year, however, JUST has strayed away from publishing their work with *in vitro* chicken and is now focusing on their recent deal with Japanese producer Toriyama to create cell-cultured Wagyu beef. JUST has stated that they are still working on *in vitro* chicken; however, it is not being publicized as much and their previous claim about releasing a product in 2018 has been dismissed (Watson 2018c). JUST has gone through three series of funding, accumulating $310 million in the past few years (JUST Inc.). The company has stated that one of their goals is to put an *in vitro* meat product on the market priced within 30% of agricultural meat. One of the ways in which they are seeking to achieve this is by recycling the medium being used and entirely eliminating serum (Peters 2018). JUST has also integrated three dimensional printing technology to aid in the tissue engineering post-culture. Their processing methods almost entirely eliminate the need for human intervention aside from quality control. JUST also allows consumers to come to their facility, watch their meat being “printed”, and select what cuts they’d like to purchase (Lamb 2018a).

Future Meat Technologies is an Israeli startup that also initially projected to bring *in vitro* meat to market in 2018. While they didn’t achieve this goal, Future Meat Technologies remains one of the front runners in clean meat technology. Similarly to other companies in the field, Future Meat Technologies is making an attempt to decrease the cost per pound of their *in vitro* meat from $363 to about $2.30-$4.50 (Nelson 2018; Peters 2018). In May of 2018 Future Meat Technologies announced a $2.2 million seed round of investment. This round was co-led by Tyson Food Ventures and has helped fund the creation of animal-free cell culture media which utilize sugars, salts, and amino acids. Tyson Foods’ executive vice president of corporate strategy and chief sustainability officer stated that the company, while they don’t see traditional meat production disappearing, is able to acknowledge the opportunity for new kinds of protein.

One of the more unique initiatives of Future Meat Technologies involves the company’s tangible plan to help shift from animal to cellular agriculture. Future Meat Technologies has plans to supply farmers with either a small number of cells or sample of tissue as well as nutrients to feed the cells and equipment for growing them. These “kits” will allow farmers to grow their own tissues in 10-18 days and then send them in to processing plants where they can be turned into a consumer product (Peters 2018; Future Meat Technologies). Particularly because of Future Meat Technologies' relationship with Tyson Food Ventures, this proposition has somewhat of a devious connotation. Many United States farmers work directly with large corporations, and have been exploited. Tyson Inc., in particular, has a history of manipulating, abusing, and unjustly capitalizing on their "independent contractors". Corporate contracts with independent farmers are dangerous in that the farmers can become highly dependent on the corporation, binding them with the fear of bankruptcy or ruin if they were to lose this security. This leaves independent farmers at risk of being exploited and entrapped by large corporations (Moodie 2017). Of course, this is not to say that any attempt to involve local farmers or communities in *in vitro* meat production would surely end in exploitation. However, the history of Tyson Inc.'s independent contracting and its relationship and similarities with this proposition from Future Meat Technologies is a potential cause for concern.

Shojinmeat, a Japanese self-described "hobbyist club", entirely makes use of the at-home cell culturing process, yet in significantly less speculative way than creating corporate contracts with individuals. The company does not require any sort of professional qualifications or expertise, nor does it limit its participants to only those stationed in Japan. Currently almost entirely self-funded, Shojinmeat works on developing "open-source DIY cell-based meat". Members join specific "clusters" that unite them based on the field in which they work or are interested in. Clusters are organized by hashtags, include "Arts & Culture", "Ethics", "Food Security", "Law", and many more (Shojinmeat Project). This approach is largely reminiscent of home-brewing communities, which bring people from hugely different backgrounds together around a singular interest. This approach, unlike the program proposed by Future Meat Technologies, has a significantly small risk of exploiting its participants. Members are considered hobbyists, not employees, as their livelihood and survival is not contingent on their participation. Shojinmeat's approach to public involvement in *in vitro* meat production, highlights the possibility of doing so wath far less risk of exploitation or corporate manipulation.

Ironically, one of the first companies to go public with the intent to produce commercially available *in vitro* meat products has yet to project when this goal will actually be achieved. Founded in December of 2015, SuperMeat is dedicated to developing clean chicken meat (Meat the Future). SuperMeat has only six major investors and has accumulated $4.2 million in two rounds of funding (the latest being in early January of 2018) (SuperMeat Crunchbase). Perhaps more interestingly, SuperMeat has also taken to Indiegogo, an online resource for crowdfunding. In 2016 SuperMeat received over 200% of its original funding goal from over 5,000 backers on Indiegogo. Significantly, the majority of these backers are "average" people who donate about $20 to the campaign. The campaign itself is still available today and is still accepting donations (Barak; SuperMeat).

The creation of SuperMeat and many of the companies following in its footsteps is largely due to the international Modern Agricultural Foundation. The Modern Agricultural Foundation (MAF) was founded in 2014. However, it made its more historic movement in January 2015 when it launched a spearhead *in vitro* chicken project with Professor Amit Gefen from Tel Aviv University. This project was one of the first of its kind and aimed to "determine the cost, time table and resources to create commercial clean chicken meat" (Meat the Future). The Modern Agricultural Foundation partners with students and researchers across the globe to help advance the understanding of *in vitro* meat as a potential consumer good. The Modern Agricultural Foundation also collaborates with commercial companies. MAF was the reason

SuperMeat was created and was integral in its funding. MAF has also taken concrete steps to inform the public about what *in vitro* meat is and its importance is to the community. In Israel, the Modern Agricultural Foundation conducts annual lectures and educational booths at local universities as well as environmental and animal advocacy events (Meat the Future).

The Modern Agricultural Foundation has also played an integral role in unifying the *in vitro* meat community. In May of 2017 the MAF organized a Cultured Meat Conference in Haifa, Israel. The conference hosted a multitude of international speakers. Among the speakers were Professor Mark Post (creator of the first *in vitro* beef patty as aforementioned) as well as many other university professors, company CEOs, research center directors, and faculty members involved with *in vitro* meat-based companies and projects. The Cultured Meat Conference sold out and the program included several meals, presentations from speakers, and question and answer panels. Sponsors of the event included many Israeli-based companies such as the Israel Institute of Technology, the Israel Innovation Authority as well as international companies such as Gold Ventures International (Cultured Meat Conference; Animal Charity Evaluators).

Several efforts to unite the many companies researching *in vitro* meat and looking to bring an *in vitro* meat products to market have been made. To-date, there have been four annual International Conferences on Cultured Meat. The latest of these conferences was held at Maastricht in the Netherlands. This conference held a similar schedule to the Cultured Meat Conference with presentations on the latest and greatest innovations surrounding *in vitro* meat technology. While the conference only made 250 tickets available it had several large sponsors. Among the sponsors included technology-related companies such as PeproTech and PAN

Biotech as well as recognized *in vitro* meat companies such as Memphis Meats (Maastricht University). Two major sponsors overlapped between the Cultured Meat Conference and the International Conference on Cultured Meat, namely, SuperMeat and The Good Food Institute (Cultured Meat Conference, Maastricht University).

Other attempts have been made to unify and present the *in vitro* meat movement to the public. The documentary *Meat the Future*, developed in association with the *Documentary* Channel, is set to release in 2020 (Facebook: Meat the Future Film). The purpose of the documentary is to shed light on the negative impacts of modern day industrial animal agriculture as well as tell the solution-focused story surrounding *in vitro* meat. *Meat the Future* also focuses on the various changes and breakthroughs in *in vitro* meat technology. A documentary is one of the first entirely consumer-driven approaches to spreading awareness about *in vitro* meat processing. The documentary itself intends to be informative rather than biased towards or against the *in vitro* meat solution to industrial animal agriculture. Producers claim they discuss the controversies surrounding *in vitro* meat products including its “moral underpinnings” as well as the very vocabulary which producers and consumers use to talk about the products. The documentary primarily follows Uma Valeti, co-founder of Memphis Meats. The documentary cites several of the company’s accomplishments including the world’s first “cell-based” meatball, the world's first “cell-based” chicken fillet and duck a l’orange. *Meat the Future* will also star Bruce Friedrich, executive director of the Good Food Institute (Meat the Future Film). The documentary, while “starring” the Good Food Institute and Memphis Meats, has no investments in its production from these companies. In fact, the documentary producers openly state that “[by making a] contribution to Meat The Future, donors certify that they do not have any financial investment in Memphis Meats" (The Redford Center). The ways in which *Meat the Future* is created, published, and received will be integral in the future of *in vitro* meat products.

As is apparent in the significant amount of research, production, and programming surrounding *in vitro* meat technology, this potential solution to modern animal agriculture is a popular one. Significantly, *in vitro* meat production and consumer-products are especially popular amongst economically and socially powerful entities. These organizations, companies, and individuals are essential in providing enough support for small startup companies to succeed, particularly when taking into account the expensive nature of *in vitro* meat research and development. The support for this technology is further justified when taking into account the impressive innovative strategies and projections many companies have regarding consumer-available *in vitro* meat. Almost every company researching or producing *in vitro* meat has several proposed solutions to create more efficient and financially viable processing techniques. These techniques along with the support from powerful people and institutions makes the production of commercially available and affordable *in vitro* meat products that can compete with traditional meat products possible.

| IV |

Public Perception and Consumer Demographics

Understanding the ways in which consumers respond to *in vitro* meat is integral in assessing its viability on the market. Particularly since *in vitro* meat technology is extremely nuanced and combines biological and technological aspects, its products harbor a significant amount of "yuck factor". The "yuck factor" has been consistently cited as an obstacle for consumer *in vitro* meat acceptance and in this context is defined as "the instinctive revulsion that many people feel at the idea of eating "unnatural" meat grown in a petri dish" (Erler 2012). Many people will manifest a disgust response when presented with the idea of consuming something created in a laboratory environment. However, understanding the basis of the "yuck factor" can offer insight into the ways in which companies, individuals, and *in vitro* meat-backers can counter this response.

The "yuck factor" is not unique to *in vitro* meat. The term was coined by Arthur Caplan, a bioethicist at the University of Pennsylvania. Caplan used the "yuck factor" to describe any instinctively negative response to a new technology. The "yuck factor" can be an extremely strong force and has taken blame for derailing various projects. For example, the "yuck factor" has prevented the implementation of projects that sought to convert wastewater into drinking water in several municipalities. The "yuck factor" may not always present in the same ways. Different variants of this disgust response may be seen depending on the situation. As aforementioned, the "yuck factor" may present itself when contemplating drinking reclaimed wastewater, but it has also been cited in discussions of human cloning (Schmidt 2008). While this response has been cited for a long time, the term "yuck factor" wasn't popularized until Dr. Leon Kass used it to describe his position against cloning human beings in 1997 (Loike 2016). Economist Åsa Löfgren of Göteberg University in Sweden has even noted a significant "yuck factor" against programs for trading carbon dioxide emission credits on the open market. No matter how positive results of a program may be, or how safe it is scientifically proven, the "yuck factor" has the ability to unhinge it (Schmidt 2008).

The "yuck factor" isn't entirely negative. On the contrary, its origins make a significant amount of evolutionary sense. Humans and animals both manifest disgust reactions, all of which have been hypothesized to be related to avoiding contagious illness. While this biological origin gave rise to the "yuck factor" itself, it is often contextualized due to a person's cultural norms (Schmidt 2008). For example, eating horse meat has been banned in California while it is still consumed throughout Africa and Asia. When California voters were polled, most viewed the consumption of horse meat repugnant, however, in Africa and Asia eating horse meat is popular and considered routine (Roth 2007). Disgust is often also associated with fear which makes the "yuck factor" an extremely powerful tool in determining an individual's aversion towards a novel concept. This power has been hijacked and used in many cases to turn the general public against propositions (Schmidt 2008).

The very field of synthetic biology is discriminated against and disliked simply because of the "yuck factor" elicited by its name. Focus groups run by the Woodrow Wilson International Center for Scholars in Washington, DC found that people tended to form negative opinions about synthetic biology upon hearing about it for the first time. Julia Moore, deputy director of the Project on Emerging Nanotechnologies at the same institution, noted the negative associations with the word “synthetic” that arose in the 21st century. Moore discussed the uncomfortable feeling many people get when hearing the words “synthetic” and “biology” together since they seem to be in such opposition to one another. Moore stated, “‘Synthetic biology’ immediately seems to conjure up threatening images, like cloning” (Schmidt 2008). Products sporting claims like “natural” and “organic”, particularly food products, are justified as better since they’re assumed to be safer, better tasting, and more sustainable. However, studies conducted by Parul Rozin, psychology professor at the University of Pennsylvania, showed that:

> “Even if we can convince people that the commercial version of a food is as safe, good tasting, and friendly to the environment as the natural version, they still prefer the natural… for most people, ‘natural’ is inherently better. But to state that sounds arbitrary, so they invent reasonable explanations for their preference“ (Schmidt 2008).

In vitro meat is already struggling to overcome the general public’s “yuck factor”. Whether it be from mistrust of food companies, unknown health consequences, ethical concern, or some other reason, the “yuck factor” is very prevalent in the discussion of consumer-available *in vitro* meat products (Camerota 2015). While a recent consumer survey showed that 66% of Americans were willing to try clean meat, that number dropped to 53% when the same participants were asked if they would eat *in vitro* meat as a replacement for conventional meat even though the descriptions are synonymous (Watson 2018a). Despite being assured that clean meat is an ethical, nutritious, and environmentally sustainable alternative to agricultural meat, still only half of participants would be willing to substitute it into their diets. This study—supported by the Good Food Institute—and many similar studies are working to find ways in which companies can advertise and describe *in vitro* meat to consumers to make it genuinely appealing.

One of the ways in which companies have manipulated the ways in which they talk about *in vitro* meat products to make them more appealing to consumers is through its name. *In vitro* meat has gone by many names: cultured meat, clean meat, stem-cell meat, test-tube meat, and more. Now taking into account the potential impact of the “yuck factor”, the power behind these words is more critical than ever before. In fact, the “yuck factor” regarding *in vitro* meat is so strong for some critics that it led them to jump to wild accusations.

The most popular of these accusations is that *in vitro* meat technology could be used in the future to justify consuming human meat products. Critics argue that since the tissue samples that will produce consumable meat products that can be obtained harmlessly from a living animal, that there is nothing to prevent corporations from using human samples over more traditional meat-providing animals? This question is particularly prevalent when the critics make accusations or assumptions about the potential for acquiring human tissue as being far cheaper and more accessible than obtaining cow, pig, or chicken tissue (Loike 2016). This slippery slope argument bears almost no scientific or biological footing, as there has been absolutely no evidence of any companies looking to create *in vitro* human meat products. However, the argument’s viability is less important than the image and “yuck factor” it has the potential to elicit in consumers. An individual conditioned to associate the idea of consuming human meat with *in vitro* meat products will more likely be put off due to the “yuck factor” attributed to the field as a whole even if that product is made from cow stem cells.

Co-CEO and co-founder of Super Meat, Koby Barak, has strongly and rather ironically stated “At SuperMeat we don’t use lab-grown meat, but cultured meat, and we are 100% supportive of the term clean meat” (Rousseau 2016). Granted, the appeal of *in vitro* meat is that its technological side gives it benefits over traditional meat. The difficulty of marketing lies in hitting the sweet spots of branding that emphasize both these positive attributes without over-technologizing the product. Consumer surveys in the Netherlands done by Mark Post show that 63% of respondents supported products labeled as “cultured beef”. Furthermore, Post found that the top reason as to why those respondents were in support of the product was because its name highlighted its stark differences from traditional meat when it came to animal suffering (Camerota 2015).

Other factors aside from the “yuck factor” also have an impact on the language use to talk about *in vitro* meat. In September of 2018 various *in vitro* meat companies converged at UC Berkeley for the Good Food Institute’s Good Food Conference. At this conference, attendees—including Memphis Meats, Tyson Foods, Kellogg’s, and many more—came to the consensus that the previously named “clean meat” would henceforth be referred to as “cell-based meat” (Good Food Conference; Watson 2018b). In discussing the advantages and disadvantages of this change in naming, those who attended the conference cited how “cell-based meat” is a more appealing label for traditional meat companies that may want to work with *in vitro* meat companies (Watson 2018b). This label leaves room for traditional meat companies to maintain their current processing agenda while also tagging onto *in vitro* meat without implying the meat they currently produce is “unclean” in any way.

With the “yuck factor”, desire for novel branding, and the influence of corporate agricultural farming entities, finding a unified way to talk about *in vitro* meat is nearly unattainable. Fortunately, since so many companies in the United States and internationally are looking to produce *in vitro* meat products, researchers will be able to see how those products hit the market and how consumers respond to and navigate various ways *in vitro* meat is marketed. However, somewhat across the board, the terms cell-based, clean, or cultured meat are preferred over *in vitro*, lab-grown, or test-tube meat for their more natural-sounding appeal.

Aside from the name itself, the ways in which corporations present *in vitro* meat products show somewhat dramatic differences in consumers’ willingness to eat them. A survey of 1,185 US adults conducted in January and February of 2018 used four different approaches to encourage consumers to accept clean meat: the first approach likened the process of creating *in vitro* meat to those that ferment yogurt and beer, the second approach focused on the various health-based problems with conventional meat that *in vitro* meat avoids, the third approach emphasized the notion that naturalness doesn’t equate with goodness, and the fourth approach—as a control—mentioned the environmental, ethical, and health benefits of *in vitro* meat. Researchers found that consumers who read the second message which noted the shortcomings of conventional meat production were significantly willing to pay more for clean meat (47% versus the 38% of those who read the control message). The data showed that “obsessing” over the naturalness of *in vitro* meat or traditional meat was less of an effective strategy than simply “focusing on positive messaging about taste and nutrition, animal welfare, and the environment” (Watson 2018a).

Just as important as the strategic marketing approaches taken by *in vitro* meat producers are the ways in which the media portrays the industry. A study done by Goodwin and Shoulders (2013) generated an overview of how media outlets presented *in vitro* meat technology and its products to the general public. The research—which explored informational themes and information sources in the United States and European Union—found several consistencies. Cultured meat news articles in both areas commonly discussed the benefits, history, process, time, livestock production problems, and skepticism surrounding *in vitro* meat production. Commonly cited information sources included academic journals, People for the Ethical Treatment of Animals (PETA), New Harvest, Winston Churchill, and first person accounts from restaurant owners or chefs. Media outlets from both the United States and the European Union used international sources as well when discussing *in vitro* meat products. The research shows media sources discussing *in vitro* meat products are generally more positive, and incorporate perspectives and opinions from proponents of cultured meat far more frequently than those from critics or agricultural sources (Goodwin & Shoulders 2013).

While media outlets are giving *in vitro* meat products a fair chance, certain demographics have more readily accepted the idea of making clean meat a part of their lives. The most consistent demographic predictor of how an individual would perceive *in vitro* meat was determined to be gender in a survey of potential *in vitro* meat consumers in the United States conducted in 2017. The data from this survey showed that self-identifying men were generally more receptive to *in vitro* meat products than self-identifying women. Men also showed generally more positive views of *in vitro* meat products than women. Only two questions of the seventeen questions asked on the survey were exceptions to these trends. Researchers Wilks &

Phillips (2017) attributed this variance to current attitudes towards meat consumption, such that eating meat is considered a masculine practice. The publication did note that while there were consistent differences between how genders perceived and responded to *in vitro* meat products, the differences were relatively small and the subsequent interpretation should be cautious (Wilks & Phillips 2017).

Wilks & Phillips (2017) also found that political affiliation was predictive of responses to the same survey. Consumers who identified as liberal/left were significantly more likely to see *in vitro* meat as more ethical and tasty than those who identified as conservative/right. Additionally, those who identified as liberal were more willing to eat *in vitro* meat regularly and as a complete replacement for farmed meat than those who identified as conservative, and were more willing to pay somewhat or much more for *in vitro* meat than traditional agricultural meat. Data also showed that liberal identifiers were more agreeable with the claim that *in vitro* meat could reduce the impact of global warming associated with traditional agricultural farming while conservative identifiers were more agreeable with the claim that *in vitro* meat farming could harm traditional agricultural farming. Those who self-identified as politically conservative were also more likely to agree with statements that *in vitro* meat is unnatural, disrespectful to nature, or will reduce the number of happy animals on earth. Wilks & Phillips (2017) noted the consistency of these trends with the general political ideologies each political party generally aligns with. Researchers claimed that being more open towards consuming and integrating *in vitro* meat products more closely aligned with the more progressive and harm/fairness-focused morality of liberal voters. These associations suggest that *in vitro* meat's ability to address animal welfare, environmental, agricultural, and other prominent issues is considered a more viable justification of implementing the technology to consumers with liberal or leftist political standings (Wilks & Phillips 2017).

Eating habits was another predictive demographic found in the consumer survey conducted. Wilks & Phillips (2017) used both diet categorisation and percentage of meat consumed to group survey participants. The data found pescatarians to be the most likely to perceive *in vitro* meat as healthy and tasty when compared to traditional meat. Vegans perceived *in vitro* meat as more natural than farmed meat, while both vegetarians and vegans found *in vitro* meat to be more appealing compared to farmed meat. Conversely, however, willingness to try and regularly consume *in vitro* meat products was lowest for vegetarians and vegans compared to other groups. This statistic remained true for willingness to eat *in vitro* meat instead of meat substitutes. Vegans were found least likely to agree with claims that *in vitro* meat products are ethical while vegetarians were the least likely to agree with sensationalist claims that *in vitro* meat could increase the potential for cannibalism (Wilks & Phillips 2017). Significantly, however, liberal-identifying individuals are more likely to be vegetarians. According to a 2011 study, 10% of liberals self-identified as vegetarian compared to only 3% of conservatives (Murphy 2011). These predetermined differences mean that, despite being more open to the prospect of *in vitro* meat, liberal people may already have chosen and adapted to an alternative diet, making them less likely to incorporate *in vitro* meat into their personal diets (Murphy 2011). Surveys that focus on interpreting intersections between identities and their correlations with attitudes towards *in vitro* meat could give insight into how these seemingly conflicting identities would manifest.

Percentage of meat consumed also turned out to be predictive of several responses in the survey. Those who had more meat in their diets were less likely to perceive *in vitro* meat as ethical compared to farmed meat and were more likely to self-identify as being unsure in response to whether *in vitro* meat is more environmentally friendly than farmed meat. Additionally, those who ate more meat were less likely to believe that *in vitro* meat consumption would reduce the impact of global warming associated with farming. Wilks & Phillips (2017) noted an "apparent paradox" in the statistical trends seen across different categories of diets. Researchers claimed that those who were already meat restrictive gave answers to the survey that indicated they were less willing to engage with *in vitro* meat. However, the same group of people reported more positive view of *in vitro* meat compared to farm meat. Wilks & Phillips (2017) attributed this trend to the fact that many of those who are already fully aware of the negative perceptions of farmed meat may already be abstaining from eating meat. Therefore, those who consistently eat meat are more likely to be unaware of the negative effects of traditional farming or may consider those problems less important. This makes sense as these perceptions would give those who eat more meat more less of a motivation to engage with an alternative meat source (Wilks & Phillips 2017).

While it is important to note trends in the effect of eating habits on consumer perception of *in vitro* meat products, media outlets have disproportionately emphasized the importance of the vegetarian and vegan perspective on *in vitro* meat. Frequently when media sources discuss *in vitro* meat products, the question of whether or not the product—if it does not require *any* slaughtering of animals—would be considered vegetarian/vegan and accepted by the vegetarian/vegan community is prominent. Traditional veganism excludes any food that comes from or is produced by animals, even honey from bees. Completely vegetarian diets, while individual restrictions vary, restrict people from consuming any products or by-products of animal slaughter (Petre 2016). While it may be a fun brain-teaser to contemplate whether or not someone who self-identifies as a vegetarian would write-off *in vitro* meat as they have traditional agricultural meat, there is minimal practicality behind this question. Since vegetarians don't consume traditional meat products, they would have far less of a motive to consume a product that replaces traditional meat products such as *in vitro* meat. Regardless of the benefits *in vitro* meat offers, these benefits are not comparable to a meatless diet as there is no meat to compare them against. Perhaps some vegetarians would eat *in vitro* meat products but would never eat traditional meat products, allowing *in vitro* meat products access to a demographic untouchable by traditional meat. This impact, however, is likely minimal (Hopkins 2015; Bryant & Barnett 2018). A study by Patrick Hopkins even labeled strict vegetarians as a "demographically negligible group" and implores resources for promoting *in vitro* meat products to focus on "empirical demographics of the consumer market and the empirical psychology of mainstream consumers" (Hopkins 2015).

Vegetarian "burgers", "hot dogs", and other meat replacement products frequently give the false impression that vegetarians desire replicate meat. However, these products have their own unique flavors, and aren't necessarily making an attempt to be "fake meat". Vegetarian burgers alone can be made using many different components—beans, corn, quinoa, mushroom—each affecting the flavor profile and eating experience of the final product. Products that are trying to mimic traditional meat products without using meat are extremely explicit in regards to this goal. For example, the Beyond Burger markets itself as "plant-based meat", and attempts to be indistinguishable from traditional meat just as *in vitro* meat products do. Importantly, however, Beyond Meat—the company behind the Beyond Burger—has explicitly stated that it's not exclusively or specially marketing its products to vegetarians (Linnane 2019). Where products like the Beyond Burger fall short, however, is that they still aren't actually meat, and are still stigmatized under the umbrella of vegetarianism.

On the other hand, a demographic factor that most media outlets have neglected in their discussions of *in vitro* meat products is religious belief. For many Jewish or Islamic people, following religious laws includes abiding by specific dietary laws (Loike 2016). Ritual/religious slaughter is part of the Jewish and Muslim religious faiths. In both of these religions, an animal must be slaughtered with a razor sharp knife without being stunned. Furthermore, Jewish religious codes require allowed animals be slaughtered by a specially trained Jewish male while Islamic religious codes prefer allowed animals to be slaughtered by a Muslim person. Ritual slaughter itself had sparked a substantial amount of controversy among many animal-rights activist groups. Several of these groups have made complaints about the use of stressful restraint devices and the animal's awareness during its slaughter (Recommended Religious Slaughter Practices). However, regardless of the ethical controversy behind ritual slaughter, the fact remains it is an impossible practice to integrate seamlessly into the production of *in vitro* meat. Without the need for slaughter could *in vitro* meat possibly be kosher or halal?

The Talmud, "the basic compendium of Jewish law and thought" has an instance that describes meat that appears miraculously from heaven. In the text, Rabbi Shimeon ben Chalafta questions whether or not two lumps of fresh meat that descended from heaven would be fit to eat. The Talmud declares the scholar's response as "nothing unfit descends from heaven".

Obviously the process of creating *in vitro* meat is not equivalent to food descending from heaven; however, part of the logic remains; if the meat is not considered a real animal, it does not require ritual slaughter. Other schools of thought, however, take issue with the fact that *in vitro* meat technically does come from a real animal. Jewish law allows a food that contains only a small amount of a non-kosher ingredient to still be considered kosher. This can only be done if the non-kosher ingredient is nullified, typically by at least a factor of 60 to 1. For example, if “a piece of non-kosher meat is mixed in with kosher meat of more than 60 times the volume of the non-kosher piece”, the entire meal can still be considered kosher (Food Nullification). It may make sense for *in vitro* meat to abide by this rule since only a small number of cells are taken from a real animal and the rest are grown (and arguably kosher). However, Jewish law also states that this rule does not apply to a *davar hama’amid;* an ingredient that establishes the form of the initial item. In this case, the “essential ingredient” can never be nullified (Shurpin 2013). These questions and statements are controversial across the Jewish community, and many more factors play into the argument. Official rulings would need to come from rabbis who are experts in Jewish law and have an extensive understanding of *in vitro* meat technology.

The Islamic community faces a similar dilemma; is *in vitro* meat halal or, if not, can it be? While not every kosher food is inherently halal, both laws regarding slaughter require the same cutting technique as well as the draining of the blood of the animal. Islamic law additionally requires that God’s name be pronounced before each slaughter and has further restrictions on what organs or parts of the carcass may be eaten from a properly slaughtered animal (Ibn Adam). The Islamic Institute of Orange County in California responded to an online question by claiming “there does not appear to be any objection to eating this type of cultured meat". Additionally, Abdul Qahir Qamar of the International Islamic Fiqh Academy in Jedda, Saudi Arabia claimed that *in vitro* meat, "will not be considered meat from live animals, but will be cultured meat" (Hepinstall Ed. 2013). While these statements are promising for the future of *in vitro* meat in the Islamic-American community, more research and conversations are essential to increase religious and public understandings of *in vitro* meat technology.

Religion also has the potential to impact the way people perceive the ethics of using *in vitro* production methods for food. Christian perception, being such a dominant religion in the United States, could have a huge impact on how the general public receives *in vitro* meat products. Being such a novel technology, there are no published statements from fundamentalist Christian figure heads that specifically discuss *in vitro* meat. However, understanding how fundamentalist Christians perceive biotechnology as a field could give insight into how the religious philosophy would be applied to *in vitro* meat. This perspective doesn't reject all forms of biotechnology. On the contrary, several Christian bioethicists encourage an optimistic outlook in regards to technology and its applications. However, there remains a strong aversion to any technological advancement that "threatens to take on godlike qualities" (Truesdale 1996). Sice *in vitro* meat processing requires the proliferation of living cells, this technology has the potential to fall into this category. *In vitro* products' face the threat of being labeled as sacreligious. On the other hand, many religious scholars have made the claim that certain kinds of stem cell research (which has the most direct applications to *in vitro* meat) aren't morally wrong (Gotquestions.org 2004). While it's possible to pull from previous statements and standings, it would be more effective to directly ask fundamentalist Christian scholars and officials about Christian morality as it relates to producing and eating *in vitro* meat. Media emphasis on these, more undetermined questions would pull in religious scholars, giving the *in vitro* meat products the spotlight in these communities and the potential to benefit for their approval.

Perhaps the most commonly cited demographic factors that has the potential to impact consumer *in vitro* meat acceptance is income level. Wilks & Phillips' (2017) United States consumer survey found income to be predictive of perceptions of *in vitro* meat. This research showed that participants with higher incomes perceived *in vitro* meat as less ethical and were less willing to try *in vitro* meat products than those with lower incomes (Wilks & Phillips 2017). This data is extremely significant when taking into account the fact that lowering the price of *in vitro* meat products is a primary concern of many *in vitro* meat researchers and proponents. In fact, *in vitro* meat's greater appeal to low income individuals may be a large reason this task is of such concern. If *in vitro* meat processing is unable to lower the price of its product, its companies are neglecting the economic demographic it most appeals to. If, as many companies have projected, *in vitro* meat products are made as inexpensive as or less expensive than traditional meat then they should be accessible to those who perceive them as ethical and are willing to try them.

Demographic information is exceedingly important in understanding who will buy *in vitro* meat products. Aspects such as the "yuck factor" and confusion surrounding *in vitro* meat technology already make its products predisposed to criticism. However, by carefully analyzing what types of consumers are willing to try *in vitro* meat products and the marketing techniques that bode most positively on its perception, *in vitro* meat has the best possible chance of being a successful consumer product.

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Moving Forward

While the applied technology is relatively new, the concept behind *in vitro* meat production dates back to the 1920s with Winston Churchill. Churchill, a politician, army officer, and writer, was able to visualize the potential for *ex vivo* meat development for human consumption (Bhat & Bhat 2011). For such a significant innovation in the field of food science, *in vitro* meat production holds ties to many other fields. These ties and their implications on how *in vitro* meat production has been developed and applied are wholly emblematic of the field of science, technology, and society.

Both techniques that have historically been used to produce *in vitro* meat were born from purposes other than food sustainability. The origin of the self-organizing technique of producing *in vitro* meat comes from the use of food technology to create an edible "fish fillet" product for long-term mission space vehicle crews (Benjaminson et al. 2002). This technique is somewhat less desirable than the scaffolding technique and has been dismissed by many *in vitro* meat researchers today as it requires a significant number of explants from muscle cells of a donor animal to generate *in vitro* meat products on a commercial level (Sharma et al. 2015). The scaffold-based technique—in which suitable stem cells are proliferated while attached to a scaffold/carrier—was first demonstrated as an art exhibit inn 2002 (Sharma et al. 2015; Cats & Zurr 2002).

While their origins extend beyond the realm of food science, *in vitro* meat technology has come a long way in regard to its sustainability-based applications. However, having a specialized purpose and a niche application is very different from entirely overthrowing the current system of meat production. Two distinct questions can help to unify, summarize, and apply the plethora of information on and surrounding *in vitro* meat technology, its products, and their limitations: can *in vitro* meat products replace traditional meat products and should *in vitro* meat products replace traditional meat products?

First, can *in vitro* meat products replace traditional meat products? Admittedly, *in vitro* meat processing is not currently where it needs to be to replace traditional meat products. However, several steps have been taken to give insight into the feasibility of this occurring in the future. *In vitro* meat products have been consistently made on a small-scale level. The first of these products was a hamburger that was engineered and eaten in 2013, only 6 years ago (Jha 2013b). Since then, fish fillets, meatballs, fried chicken, and more have been produced, sampled, and optimized (Memphis Meats 2017; JUST Inc.). New *in vitro* products are being developed daily, holding extremely positive implications in regards to the rapidly approaching future of *in vitro* meat development.

Likewise, *in vitro* production methods have been extensively developed and optimized over the past decade. Production of *in vitro* meat products like those previously mentioned have all been done in small, privatized research facilities. This level of production, while able to physically produce *in vitro* meat products, is far from the mass-production methods required to allow *in vitro* meat to replace traditional meat. However, the progress that has been made in small scale clean meat production has allowed researchers to pinpoint the necessary amendments to make both the process more suitable for mass scale, and the product as optimized as possible. Through descriptions of their innovation processes companies like JUST, Memphis Meats, Finless Foods, and SuperMeat have noted areas where their technology is currently falling short. By not rushing *in vitro* meat into mass production, companies have been able to pay close attention to every aspect of product development. This attention has allowed one of the biggest sources of controversy surrounding *in vitro* meat technology to come to light, the use of FCS as the medium in which the stem cells proliferate (Benjaminson et al. 2002). FCS, made from the blood of slaughtered pregnant cows, provides a rich supply of nutrients in which the cells can proliferate at a rapid rate (Williams 2012). Small, private, research institutions have allowed companies to explore other, cruelty-free alternatives to serum. This has encouraged research into several non-animal growth media (i.e., vegetable sera) (Pazos et al. 2004; van der Valk et al. 2004). The prospect of non-animal growth media has not been extensively explored by any other stem-cell related technology.

Small scale development has also encouraged researchers to find ways to supply oxygen to proliferated cells and *in vitro* products while three-dimensional products are being engineered. The traditional method of achieving this would be through the use of artificially produced hemoglobin. These hemoglobin—perfluorochemicals—are easy to produce, but have been shown to be damaging to animals' organs (Williams 2012; Lee 2003). On a small scale, *in vitro* meat producers have been able to create harmless artificial hemoglobin from genetically modified plants and microbes (Datar & Betti 2010). These harmless alternatives, while equally functional, haven't been utilized on an industrial scale, but their use on small scales bodes well and allows researchers to develop an extensive understanding of them before greater application (Williams 2012).

While upscaling is perhaps the most formidable opponent of making *in vitro* meat products competitive with traditional meat products, small scale production has helped laid the foundation of what works and what needs to be improved for *in vitro* meat production. Creating and integrating a non-animal based growth medium and harmless artificial hemoglobin, streamlining production, and maintaining sanitary production facilities are all necessary yet highly possible steps towards commercialization *in vitro* meat production. Upscaling may take some time, the understanding of *in vitro* meat processing researches have developed and are continuing to develop will make it possible to mass produce optimized products that have the best chance at competing with traditional meat products. Ensuring that *in vitro* meat processing is efficient, effective, and cruelty-free will keep *in vitro* meat products more appealing, accessible, and subsequently successful than traditional meat at a consumer level. Using animal-based or expensive materials in clean meat processing will directly ostracize potential customers and decrease the marginal benefits of *in vitro* meat relative to traditional meat. The companies involved with *in vitro* meat production seem aware of the importance of keeping processing cruelty and slaughter-free, which puts the final product in a better position to outshine traditional meat on the market. *In vitro* meat's unique ethical position and the value that its developers have placed on keeping the products free from products obtained by animal slaughter may have slowed the process of *in vitro* meat going to market, however, they have also maintained the appeal of the product and encouraged development in areas that would have otherwise been compromised.

From a technological standpoint, *in vitro* meat holds bright and prospects in commercialization that will put it in a position to produce enough cruelty-free *in vitro* meat to largely replace traditional meat in American diets. However, technological ability and processing is only half the battle when it comes to whether or not *in vitro* meat can replace traditional meat products. Once products are released—and even before then—media portrayal of *in vitro* meat and how the product is marketed will be essential in its success. How consumers understand *in vitro* meat is a necessary component in making its commercialization successful enough to directly compete with traditional agricultural meat.

Being a product of biological "tissue" engineering, *in vitro* meat is at risk of eliciting a "yuck factor" from potential consumers (Camerota 2015). Proper marketing, however, has the ability to play up the positive sides of *in vitro* meat to counter any initial "yuck factor" consumers may have and put *in vitro* meat products in the best position possible for success. Marketing emphasizing the ways in which *in vitro* meat is superior to traditional meat results in a positive response from consumers (Goodwin & Shoulders 2013; Camerota 2015). Additionally, adjusting the vocabulary used to discuss *in vitro* meat has a significant impact on its public perception (Rousseau 2016; Good Food Conference; Watson 2018b). With the right language, *in vitro* meat can reach a wider audience, making it more directly competitive with traditional meat. In some instances, *in vitro* meat may even be accessible to consumers that traditional meat is not accessible to. Companies are taking the time to conduct these surveys and adjust accordingly, increasing the chances that they will utilize the best methods of advertising and informing when their products go to market. This gives them a solid advantage over traditional meat, and contributes to the notion that *in vitro* meat can replace traditional meat products.

Market research has shown that consumers are willing to try *in vitro* meat, and—even considering the minimal direct-to-consumer marketing of *in vitro* meat today—many of those consumers are willing to integrate *in vitro* meat into their diets (Watson 2018b; Watson 2018a). Informed marketing to desired demographics as established by companies' market research is an essential part of putting *in vitro* meat products in a position to replace traditional meat.

Of course, marketing and technological advancements are only possible with a substantial amount of funding. However, companies involved with *in vitro* meat research and development are being backed by investors around the world. The capacity of these investments have direct connotations on how quickly and successfully *in vitro* meat will be on the market. Many companies and start-ups are looking to put *in vitro* meat products on the market in next 1-3 years, a strong possibility considering the investments they are receiving. Frequently, technological innovations fall short due to a lack of funding. *In vitro* meat products have no shortage of financial backers. From food industry giants to technology entrepreneurs, to venture capital firms, to average citizens, monetary support for *in vitro* meat production and research comes from many arenas (Troitino 2017; Memphis Meats 2017). Millions of dollars have been invested into various *in vitro* meat research facilities. This money allows the technology behind *in vitro* meat to progress, and will allow its products to be marketed in the best possible way. Despite not being subsidized by the government like traditional meat, *in vitro* meat has the financial support to make it a up and coming competitor with traditional meat.

Technologically, fiscally, and socially, *in vitro* meat most definitely has the potential not to only become a successful consumer product but to actively compete with and replace traditional meat. While this may not happen for a few more years, the path to doing so has been made clear by the amount of investment, research, and development that has gone into *in vitro* meat processing.

This leaves the second question: should *in vitro* meat products replace traditional meat products? The fact that change is imminent is apparent to anyone who closely examines the agricultural meat industry today. The world as we know it offers a limited number of resources. Human activity has impacted the world at an alarming rate over the past few decades. A large part of that effect stems from the mass industrialization of America as a country and the world. Concentrated animal feeding operations—factory farms—are responsible for massive amounts of greenhouse gasses being released. This pollution, whether it be from breeding, maintaining, slaughtering, or transporting meat and poultry, is extremely unsustainable (Greenhouse Gas Emissions). Additionally, industrial farming consumes huge amounts of food resources that could be allocated far more efficiently (Pluhar 2010; Lavelle and Garber 2008).

In addition to its lack of sustainability for the environment, industrial agriculture has been a target for animal rights activist groups for the unethical ways in which animals are kept and slaughtered (Velez-Mitchell 2014). The unsanitary living conditions for the animals have also led to a significant amount of antibiotic use. The overuse of antibiotics by concentrated animal feeding operations has been shown to contribute to growing—and dangerous—human antibiotic resistance (Factory Farms Abuse Animals). As many investigations have exposed, slaughterhouse meat and poultry workers themselves also deal with unethical treatment and working conditions (Hunzinger).

Problems with the meat industry as is are apparent, as is the fact that we need rather radical changes to ameliorate them. Yet the question remains whether or not *in vitro* meat is the best alternative. Particularly since the world of *in vitro* meat is so novel and formidable, it seems—on the surface—to be an unnecessarily extensive technological solution. To understand why *in vitro* meat is an ethical and practical choice for a traditional meat competitor, it's necessary to break down why other—perhaps more attractive—alternatives fall short.

Widespread vegetarianism is far less attainable then it may seem. Despite all extremely negative aspects of the industrial farming world being publicized, American meat and poultry consumption remains extremely high. Meat is a part of American social and food-related cultures, with Americans eating four times as much beef as the rest of the world (Waite 2018). The rise of the "conscious consumer" has had little to no impact on meat and poultry consumption (OECD 2018). Publicizing the problems with the meat industry haven't significantly influenced the rate of vegetarians, and we are a long ways away from increasing the rate to a degree with a substantial impact on the environmental and ethical issues caused by the meat industry.

Decreasing government subsidization for meat products or increasing federal rules and regulations concerning the meat industry as an effort to influence widespread vegetarianism or less problematic farming methods also carries their fair share of problems. First, the meat industry's history of political affiliation and influence is likely to make passing laws or regulations not an easy task. Second, if laws were passed or government subsidization was decreased, the price of meat would skyrocket. Companies wouldn't be able to cut as many ethical or environmental corners in their production methods, subsequently increasing the cost of their final products. Meat products are cheap options with a relatively significant amount of nutritional density for many Americans (Rampell 2010). Fresh fruits and vegetables are often inaccessible and extremely expensive, making a meat-rich diet one of the only nutritional diets low-income Americans—and families—can afford (Leonhardt 2009). Increasing the price of meat products would increase the rates of food insecurity across the United States. Likewise, humane farming methods are far more expensive than CAFOs, and produce far less product. Any changes that are made in the meat industry must be done so with families who rely on meat products for cheaper sustenance in mind.

The economic accessibility of, social dependence on, and trends concerning meat and poultry consumption in the United States illuminate several problems with the possibilities of widespread vegetarianism, increasingly strict meat industry regulations, or humane farming as long-term solutions to the environmental and ethical instability of the industrial farming industry. While no solution is perfect, *in vitro* meat offers a way around some of these problems by appealing and being accessible to a large variety of people. *In vitro* meat—as marketed by companies looking to make consumer-products—would entirely eliminate the ethical problems of traditional meat. Environmentally *in vitro* meat would still need transportation and production facilities which would likely cause significant pollution. These effects, however, would presumably pale in comparison to the current environmental harms necessary to maintain industrial meat production.

Financially, *in vitro* meat has seemingly infinite investors. These investments are helping to decrease the price of the final product to—as proponents claim—be as or more cost-effective than traditional meat. This price reduction, unlike traditional meat, is also being achieved without the advantage of government subsidization. *In vitro* meat, therefore, would be accessible to low-income households, and still be providing the nutritional density traditional meat does. Unlike other alternatives to the current meat industry, *in vitro* meat allows consumers to eat what they want, access the products, and do so with the comfort of its processing being ethically and environmentally sound.

In totality, *in vitro* meat is on track to being an incredibly successful consumer product in the coming years and it would both feasible and beneficial to the general public for *in vitro* meat products to largely replace traditional meat products. The prospects of *in vitro* meat are emblematic of the ways in which the human race can and must adapt and assimilate in constantly changing environments. While people may reminisce about how much better agriculture was when it was controlled by independent farmers, those days are far behind the times. We need a feasible and holistic solution to the problems within and around the meat industry. *In vitro* meat is the perfect way to have our meat and eat it to, and I believe that *in vitro* meat production both can and should begin making traditional meat products obsolete within the coming years.

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