CellAgri

An Introduction to Cellular Agriculture

Ahmed Khan

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About The Author

Ahmed Khan is the founder and editor of CellAgri. A news and research startup that aims to be the homepage of the emerging field of cellular agriculture. CellAgri's platform tracks all the major and upcoming players in the field. Providing them the ability to post and share their latest news and job openings.

Ahmed first learned about cellular agriculture while studying at McGill University in Montreal, Canada, and has been passionate about the field ever since. If Ahmed is not writing or working on CellAgri, Ahmed is a huge cricket fan and loves to watch and play the sport!

Author's Note

In 2013, food critic and writer Hanni Ruetzler took a taste out of a dish costing more than **$300,000**. She remarked how it was "*close*" to tasting like real beef. The dish in question was not a plant-based meat alternative; it was in fact real beef - beef that was made in a lab!

This taste test was the first lab-grown beef burger. It was created by Dr. Mark Post and his cellular agriculture research team in the Netherlands.

Without any animals.

Since the first taste test, **cellular agriculture** is being explored as an alternative to the present livestock agricultural system. Many inspired researchers and entrepreneurs have entered the field looking to change the *future of food*.

I first learned about cellular agriculture through the best accident ever. I was promised a meal if I sat through a random presentation. It wasn't the best dinner, but that presentation changed everything.

I learned about how cellular agriculture is a field of growing animal products from *just cells.* And that blew my mind.

Dr. Mark Post and the first cell-cultured meat beef burger

I had to join the field and become part of the movement changing food forever. But how?

For any movement to gain traction, there has to be a news source. A source of the latest updates from all the players. A one-stop source for anyone who wants to learn and keep up with the field.

I founded CellAgri in 2017 to serve as the news and insights platform for the field. CellAgri tracks all the players and companies in the field to provide the latest updates in cellular agriculture, from research to the companies bringing products to market.

Through the book, I hope you will get a complete introduction and overview to the field. The book is a collection of modified and updated articles that will help you learn about *what* this field is, *who* is in it, *how* it works, and *why* the field matters.

For the future of food.

Biology 101

Biology is the study of life. From the emergence of life to the intricate details of our DNA, biology covers a wide range of topics. And it is the source of all emerging and innovative biotechnologies.

Thanks to advancements in cutting-edge technology, scientists and researchers can bring science fiction to life: cell-grown foods.

But what is the science behind this, and how is it even possible? Here's a basic overview of cell biology to follow along!

The Cell

The cell is a basic unit of life, and we are made up of trillions of cells!

Typically, cells specialize into different types of cells to help carry out a function. Brain cells, muscle cells, skin cells. These are all different cell types that make up the body. And each different type has *differentiated* characteristics that help it carry out a different function.

Yet, how do all these different cell types emerge?

Cell Division

A new cell comes from the cell division of an existing cell. A cell will divide into more cells through a process called self-replication (also known as mitosis). A cell will only divide under the right conditions. This is when the cell has enough nutrients, energy, and growth factors to start dividing.

In the laboratory, scientists use cell culture media to grow cells. The cell culture media, which includes the cell culture *serum*, provides all the nutrients and growth factors that the cells may need to replicate. In this way, the cell culture media makes the cells believe they are still in its body and will grow accordingly, if all the right conditions are in place.

But not all cells can divide. Most cells in the body lose their ability to divide as they get older. Most cells can only divide a certain number of times in their lifespans.

The Stem Cell

A **stem cell** is a unique type of cell that has the ability to divide to produce more of itself via self-replication. These new stem cells can also self-replicate to produce more stem cells. A stem cell also has the unique ability to become a different cell type (like a muscle cell or a brain cell) through a process called **differentiation**.

Yet, once again, not all stem cells are the same. Early on in development, stem cells have the ability to self-replicate indefinitely and to differentiate into many different cell types. Typically, stem cells found in most adult tissues (like satellite cells in muscle) have a limited number of self-replications in their lifespan and can only differentiate into specific cell types.

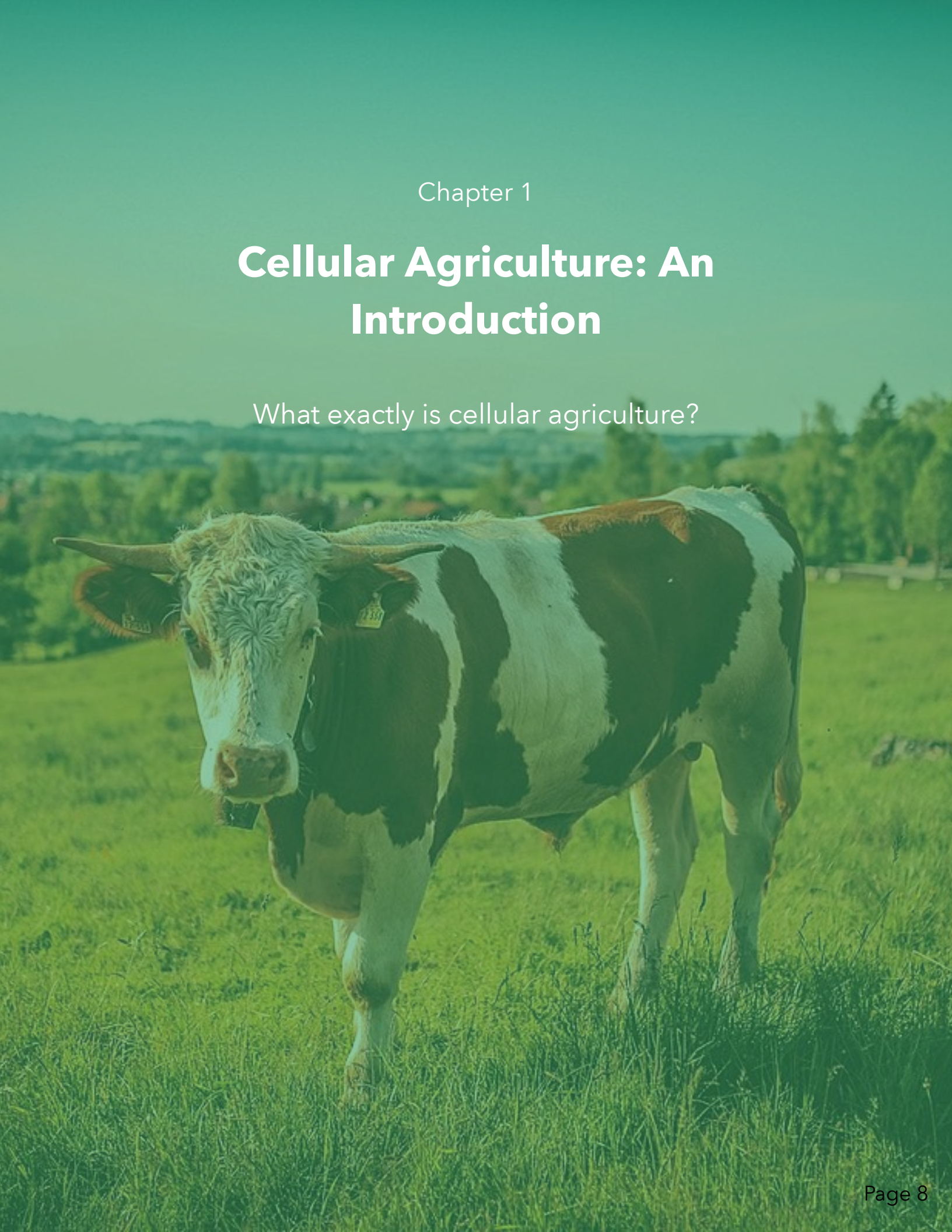
We cover other scientific terms as we go along (including a list of 6 terms that will help you understand cellular agriculture).

If this biology introduction leaves you with questions, please feel free to email me at ahmed@cell.ag. I am also attaching a few resources at the end that will give a more detailed introduction to cell biology.

Chapter 1

Cellular Agriculture: An Introduction

What exactly is cellular agriculture?



Cellular Agriculture: An Introduction

WHAT EXACTLY IS CELLULAR AGRICULTURE?

Cellular agriculture is the field of growing agricultural products directly from cell cultures instead of using livestock. At the moment, the primary research has revolved around growing meats (beef, pork, poultry) as well as animal products (milk and egg white) in cell cultures. Instead of raising, for example, a cow from birth for milk and meat, cellular agriculture presents an alternative way to get the same product without all of the problems associated with raising livestock.

HOW DOES IT WORK?

Cellular agriculture can be broken up into two categories: **cellular** and **acellular** agriculture. In this context, cellular agriculture refers to growing agriculture products that are based on living or once-living cells, such as meat. To put it simply, growing meat is the process of taking the cells that make meat from the animal of interest and growing them in a cell culture media to become meat. The cell culture media and how the cells are grown are important aspects in this process, because they help the cells become the *same* meat that comes directly from animals.

Acellular agriculture involves growing and harvesting a product that the cell cultures make. This is used to make products such as milk and egg white. Just like egg white, milk is a mixture of different proteins and fats. These different components can be grown without using animal and, instead, by using microbes, like yeast. For example, to grow casein, which is a key protein in milk, a copy of the casein gene from a cow is inserted into yeast. The yeast will then make many copies of the specific animal's protein (casein from a cow) that can be used to formulate dairy milk that is identical to the milk made from a cow. Without requiring a cow.

The process of using yeast to grow a protein of interest is not novel to cellular agriculture; this process has been used since 1978 to make insulin for diabetes treatment. It is also used to make rennet and vanillin.

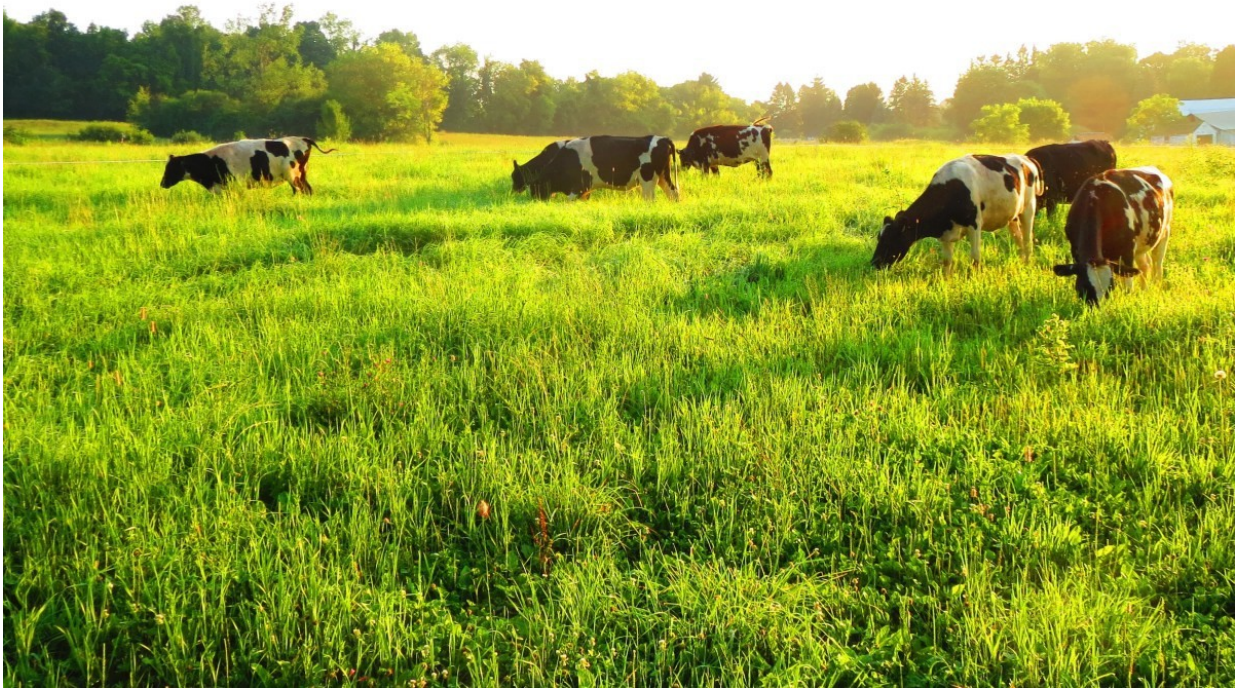
WHY IS IT IMPORTANT?

Besides the incredible fact that it *is* possible to make animal meat and milk without requiring an animal, cellular agriculture is **critical** in developing a sustainable livestock agricultural system. The present system has produced enough to meet current demands. But it will not be able to keep up with future demands. Especially with a growing population.

It is predicted that the global population will be between 9 and 11 billion people by 2050. The global demand for meat will skyrocket from 60 billion animals in 2016 to 100 billion animals in 2050.

How can a system that already requires so many resources sustainably produce that much meat?

The growing global demand for meat and animal products illustrates that people are not ready to change their eating habits from meat to plant-based alternatives. Instead of urging people to eat more plant-based diets, the next best option is to find a better way to produce meat. That is exactly what cellular agriculture offers.



ENVIRONMENTAL REASONS

It is shocking how many resources, like land, water, and electricity, are consumed in livestock agriculture. To produce one 8-ounce (0.23kg) steak, not only is 1.6 kg of feed required, the production process requires enough energy to fully charge one laptop *sixty* times as well as 3,515 liters of water. In addition, 4.54 kg of carbon dioxide is released into the air as various greenhouse gases, which is the equivalent of the emission of 2 liters of gasoline.

These numbers reflect the resources required to produce **one** 8-ounce steak. Not an entire cow.

After cattle farming, sheep and pig farming consume the next most resources, respectively, followed by poultry farming.

The large amount of resources consumed by livestock agriculture reflects its large environmental footprint. Approximately 25% of the earth's surface is taken up for livestock farming. This is approximately 70% of all land used for agriculture. The production of animal products constitutes about 30% of all fresh water usage.

Most alarmingly, livestock agriculture generates 14.5% of all greenhouse gas emissions. This is higher than the global transportation industry emissions of 12%. Considering all that has been done in the automobile industry to reduce carbon emissions, it is **shocking** how livestock farming contributes such a significant proportion of all greenhouse gas emissions with little done to reduce it. Until now.

Cellular agriculture has the potential of helping reduce global greenhouse gas emissions as well as promote more responsible uses of natural resources.

Compared to livestock agriculture, cellular agriculture provides an alternative that is more environmentally friendly and more sustainable. Meat produced via cellular agriculture would use approximately *less than a tenth of the land and water*. This meat would also produce significantly less greenhouse gas emissions.

ANIMAL WELFARE

Beyond the environmental impact, cellular agriculture would impact animal welfare. Without requiring livestock, cellular agriculture (obviously) reduces the number of animals used in the food production process.

Furthermore, as the global demand for meat increases, large factory farms would be put under more pressure to produce even more animal products. It's likely that animal welfare conditions would worsen from their current state, including increased confinement and imperfect slaughter conditions, to meet the demand. By providing another method to meet the global demand without worsening livestock conditions, cellular agriculture provides an opportunity to improve livestock welfare.

HUMAN HEALTH

Regarding human health, meat produced via cellular agriculture would not be fed the large amounts of antibiotics given to animals. In the US, nearly 80% of all antibiotics sold go to animal agriculture. Antibiotic usage in animal agriculture has led to various health issues, such as the rise of antibiotic resistant bacteria.

In addition, most bacterial contaminations that cause food-borne illnesses, such as E. coli and salmonella, often occur through interaction with infected animal feces. By cutting out livestock in cellular agriculture, there will be no E. coli or salmonella from livestock that could contaminate the meat or other products.

CONCLUSION

Prior to cellular agriculture, there had not been an environmentally friendly and sustainable alternative to the livestock agriculture system for meat. While research projects the energy required to produce meat via cell cultures is greater than conventional poultry, cellular agriculture is more sustainable when comparing land and water use and greenhouse emissions. It is no surprise that lab-grown meat has also been called "*clean* meat".

There are still many obstacles to overcome before cellular agriculture products become commercial. One of the most difficult ones to overcome will be challenging any negative *public perception* of food that come from cell cultures instead of from animals.

To overcome this, it will be important to inform the public on what cellular agriculture is and how this field provides a solution to an unsustainable livestock agricultural system. It will also be very important for all actors in the field to be transparent and clear about all of their scientific findings and all aspects of the manufacturing processes.

Chapter 2

6 Terms You Need to Know to Understand Cellular Agriculture

Here are a few more terms that will help make cellular agriculture easy to understand!

6 Terms You Need to Know to Understand Cellular Agriculture

Here are a few more terms that will help make cellular agriculture easy to understand!

Cellular Agriculture

It makes sense to start off with this definition!

Cellular agriculture (commonly abbreviated as **cell ag**) is the field of growing animal products directly from cell cultures instead of using livestock. Eliminating the need to use animals. The main research has revolved around growing animal meats (such as beef, poultry, and fish) as well as animal products (like milk, leather, and egg whites) in cell cultures. So instead of raising a cow from birth for milk, meat, and leather, cell ag presents an alternative way to get the same animal products without all of the problems associated with conventional livestock agriculture.

Cellular agriculture can be broken down into two categories, based on how the cell cultures are used: cellular agriculture (where the actual cells are harvested, like for meats) and acellular agriculture (where a product that the cell cultures make and *not* the actual cells are harvested).

Cultured Meat

Cultured meat refers to the meat grown in vitro from cell cultures via cellular agriculture. Cultured meat is also referred to as **cell-based meat**, clean meat, lab-grown meat, and in vitro meat. To grow cell ag meat, muscle cells are taken from the animal of interest and these cells are grown in a cell culture media. The cell culture media and how the cells are grown help the cells develop into the *same* meat that directly comes from animals.

The first taste test for cultured meat occurred in 2013 when Dr. Mark Post and his team created the first lab-grown beef burgers for more than **$300,000** each. Since then, the cost of producing a burger has dropped significantly. In 2016, Memphis Meats became the first cell ag company to make the cell-based meatball. In March 2017, Memphis Meats also became the first company to produce cell-based poultry meat (chicken and duck). Later in 2017, Finless Foods became the first company to produce cultured fish meat.

In September 2018, New Age Meats introduced the world to the first cell-based pork sausage. And in December 2018, Israeli startup Aleph Farms surprised many to produce the world's first cell-grown beef steak.

Cell Cultures

Cell cultures refer to growing cells in a controlled environment (like a laboratory) outside of where the cells would normally be found. In order to survive and replicate, these cells are placed in a cell culture serum that contains all the nutrients that will help the cells grow.

In cellular agriculture, cell cultures are used to grow and produce the animal products without requiring animals. One of the key obstacles ahead in cell ag is scaling production of cell cultures to get from lab to market. For example, cell ag researchers are looking for the best cell lines to grow in cell cultures and eliminate their dependence on animal-derived cell culture serums.

Conventional Livestock Agriculture

Conventional livestock agriculture refers to traditional animal agriculture and using animals to produce animal products. While this is the norm, one of the main driving forces for cellular agriculture is the need to develop a sustainable system for animal products. The global population will grow to be between 9 and 11 billion by 2050. The demand for animal products will nearly double. With an increased need for meats and other animal products, conventional livestock agriculture is not sustainable to meet the growing demand due to its resource demand and environmental impact.

Bioleather

Bioleather is a term coined by Modern Meadow to describe their sustainable leather made via cellular agriculture. Modern Meadow is a company that uses cellular agriculture (more specifically, *acellular agriculture*) to grow the protein collagen that is the main component of leather.

Unlike conventional leather, Modern Meadow produces collagen that can be molded into different shapes and sizes. Other leather properties can be modified too, including the texture, strength, and durability of the material. This means that Modern Meadow's bioleather can be customized to provide leather designers the specific qualities they would like without having to worry about the traditional leather supply chain.

Growing animal collagen directly for leather is much more sustainable than the current leather production system. By overcoming the need for cattle and the chemically intensive steps in leather tanning, bioleather avoids and reduces the majority of carbon emissions with leather production and be more environmentally friendly.

Plant-based Meat Alternatives

Plant-based meats alternatives are products that use plant-based ingredients to mimic and replicate the flavor of meat. In the past, many of these veggie burger attempts have not been successful in attracting the conventional meat consumer. They just don't have the same taste or texture as conventional meat. More recently, companies like Impossible Foods and Beyond Meat have created unique plant-based meat products that have the same taste and texture as conventional meat.

While plant-based meat alternatives also aim to reduce the environmental impact of conventionally produced meat, these are products are **not** the same as cell ag meat products. Cell-based meat consists of actual animal muscle tissue, grown without requiring animals in the process. Plant-based meats are entirely plant-based and do not contain any animal components. Ultimately, however, both cell ag and plant-based meats are working towards the same goal: a healthy and sustainable source of animal products

Chapter 3

From Lab to Market

There are four key areas that need to be further developed to scale production, and this section will highlight these different parts of production

From Lab to Market

In 2013, when Dr. Mark Post's team developed the first cultured meat burger, it took three lab technicians *three months* to grow and put together 20,000 cow muscle fibers. To make the first $330,000 lab-grown burger. In the coming years, several cellular agriculture companies are preparing to release their first commercial product. Scaling the production process will be important to ensure that cell ag is a commercially viable option.

There are four key areas that need to be further developed to scale production, and this section will highlight these different parts of production.

Cell Lines

Researchers are looking for **stem cell** lines from different animals that will (*ideally*) divide indefinitely into more cells. These cell lines would then become the stable source of all other stem cells and differentiated cells that produce cell-cultured meat.

Stem cells are unique because they have the ability to produce more of itself via self-replication or to produce cells that become different cell types via differentiation. At the moment, to produce cell-based meat, some researchers are using cells found in muscle called satellite cells (Yes, these cells are also in us!). When activated, the satellite cells will either self-replicate to produce more satellite cells or differentiate into muscle fiber cells that can become the meat product. The problem with these cells, however, is that satellite cells have a limited number of self-replications in their lifespans.

Once a stable cell line is found and becomes widely available for animals of interest (like cows, pigs and chickens), the sourcing of stem cells to make cell-cultured meat will no longer be an obstacle.

Cell Culture Media

The **cell culture media,** is the nutritious mixture that cells grow in, which includes the cell culture *serum*. The cell culture media provides all of the nutrients and growth factors that cells may need to replicate or differentiate into another cell type. There are two main obstacles in scaling cell culture serum: its sourcing and price.

In many scientific labs, a common cell culture serum used to grow cells is fetal bovine serum. Not only would this still involve animal sourcing in the production process, fetal bovine serum is inconsistent from batch to batch as well as very costly. Animal-free serums have been developed for medical purposes, but the problem of costliness remains for scaling production.

The development of an inexpensive and animal-free growth serum for cell lines has once been described as the *Holy Grail* for cellular agriculture companies, as it is one of the main obstacles to scale production. Further innovation and research are required to find a cost-effective solution that would make scaling cell ag production feasible and affordable.

Bioreactor

A bioreactor is the chamber that houses the cell culture serum and scaffolding to promote the growth and differentiation of cell lines to cell-based meat. Essentially, bioreactors are the chamber where all the parts of scaling cellular agriculture production come together to form the finished product. Bioreactors will likely be large tanks that would be like large brewery tanks.

Currently, no large-scale bioreactors exist that would accommodate commercial scaling for cultured meat. Research is currently investigating how to scale contemporary bioreactors and modify them for growing meat.

Scaffolding

When a building is under construction, it is surrounded by scaffolding for structural support. In this way, the scaffolding outlines how the building will look like.

Similarly, in cellular agriculture, scaffolding provides structural support to cells by outlining the composition and shape of cell-cultured meat. This is important to make sure that the cells grow into muscle fibers that have the same taste, texture, and shape as conventional meat. Scaffolding also promotes the growth of larger muscle fibers needed to scale production.

Further innovation is required to create scaffolding to grow complex meat tissues like steaks. Steaks consist of different amounts of muscle, fat, and connective tissue, and a complex scaffolding will have to be able to replicate their appearance and composition.

Conclusion

In the future, a stable and immortal stem cell line will be produced by obtaining relevant cells from the animal of interest. This cell line is stable and a constant source of stem cells, so animals are no longer required in the production process. These stem cells are grown in an inexpensive animal-free cell culture media in a bioreactor. As the stem cells self-replicate and differentiate to muscle fibers and other cell types, the cells detach and mature into cell-cultured meat.

There is a long way before this idealistic situation can become a reality. Not all topics need to be solved before the first products come to market. Starting with cell-cultured ground beef or poultry avoids many of the issues relating to scaffolding.

Chapter 4

The Products Leading a Revolution

Cellular agriculture will soon be available at a store near you!

The Products Leading the Revolution

While some actors and companies believe that cell-cultured meat will be on the market at the earliest by 2021, others are working to get to market faster. We highlight some of the upcoming products in each sector and when to expect them!

BOLT THREADS' SILK TIES, TOQUES, AND LEATHER BAGS

Bolt Threads is a clothing startup that uses animal-free spider silk to make clothes. By using yeast to produce spider silk. Bolt Threads has already released a few products in limited amounts. In early 2017, Bolt Threads made the first spider silk necktie and sold 50 of them for $314 each. In December 2017, Bolt Threads partnered with the Best Made Company to make toques and released a limited amount of Bolt Threads x Best Made Caps of Courage.

In 2018, Bolt Threads announced its latest product line: *Mylo*. Unlike their other products, Mylo is not made from spider silk. It's leather, made from mushrooms. Licensing the technology from Ecovative Design, Mylo is a leather material produced from mycelium, the root structure of mushrooms. In September 2018, Bolt Threads announced the first commercial product from the Mylo line: The Driver Bag. Each bag is cut and sewn by hand in partnership with Chester Wallace, a bag company in Portland, Oregon.

Bolt Threads

Mushroom-based leather and spider silk ties.

GELTOR'S COLLAGEN

Geltor is a startup that uses cell ag to create animal-free gelatin by using yeast to produce the protein collagen. Collagen is the main component of gelatin and is used in a range of other products, such as cosmetics. In May 2018, Geltor won the CEW's Award for Innovation for 2018 for their first cosmetic product: *N-Collage*, a collagen skincare product. It's great to see that Geltor's innovative work for a sustainable source of collagen has earned them recognition in the cosmetic world.

WILD EARTH'S DOG TREATS

Wild Earth is the first pet food startup to use cellular agriculture to produce sustainable pet food. As of October 2018, you can pre-order their first product from their website: koji-based dog treats! Koji is a breed of fungi that is found in miso soup and soy sauce. By using koji, Wild Earth addresses the problem of "low-quality of protein" found in pet foods. Wild Earth first began limited releases of their koji-based dog treats in July 2018. They plan to release more pet foods in 2019.

JUST MEAT

Not everyone is waiting until 2021 to release cell-cultured meat. Just ambitiously wants to be the first company to have their product on the market. In 2017, Josh Tetrick of Just (formerly Hampton Creek) announced that Just will release their first cell-based meat product by the end of 2018!

Spoiler: they didn't. Just now aims to have their first product released in 2019. Let's see what they can deliver this year.

BIOLEATHER

Modern Meadow is a company that uses cellular agriculture to grow animal-free leather to make clothes and other leather goods. Unlike conventional leather, Modern Meadow's 'bioleather' is in liquid form (essentially, a liquid leather) that can be molded into different shapes and sizes. Modern Meadow created a prototype t-shirt for its brand Zoa and displayed it at the Museum of Modern Art in New York City and hope to have their first finished products released by 2019. It's expected that high-end brands will be the first designers to incorporate their sustainable leather into production.

FINLESS FOODS AND BLUEFIN TUNA

Finless Foods is the first company to use cellular agriculture to grow fish meat from cell cultures. Finless Foods plans to release a limited amount of its Bluefin tuna by the end of 2019. Bluefin tuna is a type of fish that has been overfished for so long that one Bluefin tuna usually costs **over $100,000** in Japan. Once production is scaled, Finless Foods can expand into producing cell-based meat of other fish species also under threat from overfishing.

ANIMAL-FREE DAIRY MILK

Perfect Day Foods make cow-free dairy milk via *acellular* agriculture. Instead of rushing into the milk aisle, Perfect Day initially plans to sell their product to other businesses. In November 2018, Perfect Day announced a partnership with food ingredients company Archer Daniels Midland to scale production. Perfect Day cofounder and CEO Ryan Pandya also shared that their first product will an animal-free **whey protein**, which will be ready as early as *this year*.

CHICKEN-FREE EGG WHITE

Similar to Perfect Day, Clara Foods uses *acellular* agriculture to produce chicken-free egg white. Clara Foods plan to sell their product to other businesses to use as an ingredient. With large corporations like McDonalds, Nestle, and Walmart committing to 'cage-free eggs' in the next 5 to 10 years, it is possible that scaled production of cell ag egg whites could provide a way of doing that.

LOOKING TO THE FUTURE

Beyond these companies and products, there are other companies that plan to have their own cell ag products released later on. Beyond any regulatory issues and other obstacles, one of the main hurdles ahead for cellular agriculture is scaling production to be commercially viable. Once that is developed, we are likely to see more cell ag products in the near future!

Chapter 5

3 Misconceptions about Cell-based Meat

What is it really?

3 Misconceptions about Cell-based Meat

Cultured meat.

The USCA doesn't want it to be considered meat. The NCBA says it should count as meat, but should be as strictly regulated as slaughterhouses.

Some call it *clean meat*, others cell-based meat. But what is it really?

There is some time before cell-based meat gets to market, but there are already quite a few misconceptions about it. This section will address three of the main misconceptions surrounding cell-based meat.

MISCONCEPTION #1: IS IT MEAT?

According to the Oxford Dictionary, meat is defined as "the flesh of an animal, typically a mammal or bird, as food". The US Cattlemen's Association (USCA) support this definition and have petitioned the US Department of Agriculture (USDA) to redefine meat as the flesh of an animal that has been raised, slaughtered, and harvested in the 'traditional' manner.

This raises the question: if animal 'flesh' can be raised *without* requiring the animal, can it still be meat?

People in cell ag believe it can.

Cell-based meat is derived from the same source of cells (stem cells) that become meat in animals. This means that the same cells that make up conventional meat from a raised animal will make up cell-cultured meat: animal muscle cells, fat, and connective tissue that adds to the flavour. If conventional and cell-cultured meats appear similar under a microscope (because they're compositionally the same), can cell-based meat really be excluded from the definition of meat? Should there be any difference in its labelling?

While the USCA doesn't believe cell-based meat qualifies as meat, others in the meat industry think otherwise. The larger National Cattlemen's Beef Association (NCBA) believes cell-based meat meets (no pun intended) the definition of a meat product and, therefore, the United States Department of Agriculture (USDA) should be in charge of regulating it as *strictly* as they regulate beef slaughterhouses.

In addition, Tyson Foods and Cargill, the largest meat and poultry producers in the United States, have invested in cell-based meat company Memphis Meats. Memphis Meats is the first cell ag company to produce cell-grown poultry as well as the first meatball.

While the meat industry will continue to debate what qualifies as meat, the support of large meat corporations investing in cell-based meat shows that it can be a way to produce meat in the future.

MISCONCEPTION #2: WHO'S REGULATING CELL-BASED MEAT? IS IT EVEN SAFE?

One of the first questions many people have about cellular agriculture and cell-based meat is who is in charge of marking sure it's safe? In Europe, new regulation has put the European Commission in charge of approving and regulating novel foods, including cell-based meat. In the United States, where most cell ag companies are based, the question was only recently solved.

As the NCBA and USCA have noted, the USDA regulates and oversees animal products like meat, milk and eggs. But what if those animal products are coming from cell cultures, a field that the Food and Drug Administration (FDA) would have oversight over?

In October 2018, the USDA and FDA held a joint public meeting over the regulation of cell-based meats. During the two-day event, the two agencies stated that they intend to *jointly* regulate these products. This will be the *first* instance where both agencies are in charge of regulating a field of products. It will be interesting to see what pathway the two agencies develop to move the field forward.

In regard to safety, one of the names that cell-based meat has been branded as is *clean meat*, and that name is meant to reflect the health and environmental benefits of it. In addition to the environmental benefits (animal agriculture emits 14% of all greenhouse gas emissions), cell ag meat will likely be produced in sterile environments where they will be free from microbial contamination. In the future, more studies and research will be conducted to ensure the safety of cell-grown food products as well as its environmental impact.

MISCONCEPTION #3: IS CELL-BASED MEAT A GMO?

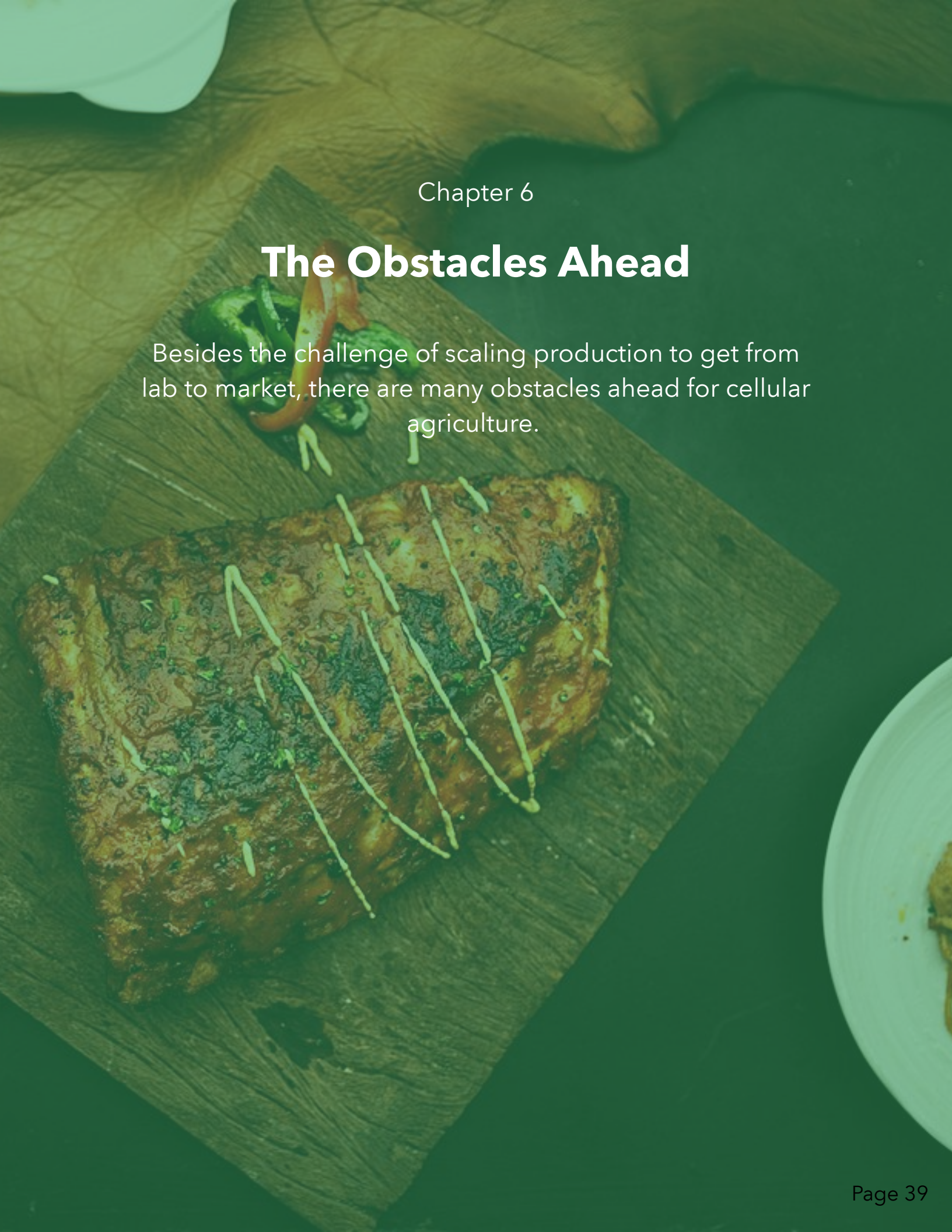
GMO stands for genetically modified organisms. It involves the science of inserting the DNA of a gene of interest into the DNA sequence of another organism to produce a specific outcome.

Since cell-based meat comes from unmodified animal cells, it is not considered a genetically modified food. Therefore, cell-based meat **will not** contain genetically modified organisms.

Having said that, there are some valuable lessons that cell-based meat (and cellular agriculture) companies can learn from the launch of GMOs. And avoid making the same mistakes.

There is still a lot of public mistrust over GMOs. When genetically modified foods first came onto the market, there was little public education or information about the new technology. Are GM foods safe and healthy to eat? And what will happen if I eat them? With little public information about the new technology (and associated food), other actors filled the gaps in information – and *not* to promote a new technology that they didn't know much about. What emerged was a public that mistrusted and feared a new technology in their food.

The cellular agriculture space is learning from those lessons. All the major players in cell ag are trying to be transparent by showing their technology and the processes involved in making animal products via cell ag, including cell-based meat. With this so-called "radical transparency", cell ag will not be vulnerable to the same downfalls as GMOs.



Chapter 6

The Obstacles Ahead

Besides the challenge of scaling production to get from lab to market, there are many obstacles ahead for cellular agriculture.

The Obstacles Ahead

From the first $300,000 burger in 2013, a lot has changed in cellular agriculture. Since that taste test, cellular agriculture companies have gotten traction and have gone beyond their own taste tests.

Beyond cell-based meat, cellular agriculture has gained momentum elsewhere too. Modern Meadow exhibited a proof-of-concept shirt designed with their cell ag bioleather at the Museum of Modern Art in New York City. Perfect Day Foods and Clara Foods are fielding interest from other companies to use their animal-free dairy proteins and egg white proteins, respectively.

Clearly, cell ag has made progress.

Besides the challenge of scaling production to get from lab to market, there are many obstacles ahead for cellular agriculture.

REGULATORY ASPECTS: WHO'S IN CONTROL?

One of the first questions many people have about cellular agriculture is who is in charge of making sure it's safe? In Europe, new regulation has put the European Commission in charge of approving and regulating novel foods, including cultured meat.

In the United States, where most cell ag companies are based, **the answer was only recently settled.** Since the start of 2018, there has been a regulatory turf war between the US Department of Agriculture (USDA) and Food and Drug Administration (FDA) over who will regulate cell-cultured meat. In May 2018, a congressional subcommittee nearly gave the USDA regulatory control over cultured meat, but the bill did not pass. The following month, the FDA unilaterally announced that they will be in charge of regulating *all* cell-based meats.

In August, Memphis Meats and the North American Meat Institute proposed a joint regulatory pathway forward in which both the USDA and FDA regulate cell-based meats. The FDA would be responsible for ensuring cell-based meats undergo pre-market safety tests while the USDA would be in charge of monitoring the meat facilities. This is the first time a cell ag company and a meat industry player have come together to support a regulatory pathway that could appeal to both fields. And it seemed to work.

In October, the USDA and FDA announced that they will *jointly* regulate cell-based meats. Using their expertise in their special fields, this may be a way forward to bring cell-based meats to markets.

Having said that, there are still many questions about what cell-cultured products would look like at scale. Will *antibiotics* be required to keep the cell culture serum sterile? How will the products be *labelled*? And, most of all, what will the product even be called?

Cell ag companies with acellular products, like Perfect Day's cow-free dairy proteins and Clara Food's hen-free egg white, could skip FDA's regulatory safety assessment altogether. This can be done by showing their products use procedures and ingredients that have already been generally recognized as safe (GRAS). Since egg white proteins and milk proteins like casein and whey are already deemed GRAS, these two companies may be able to skip FDA safety approval by using pre-approved GRAS yeast strains.

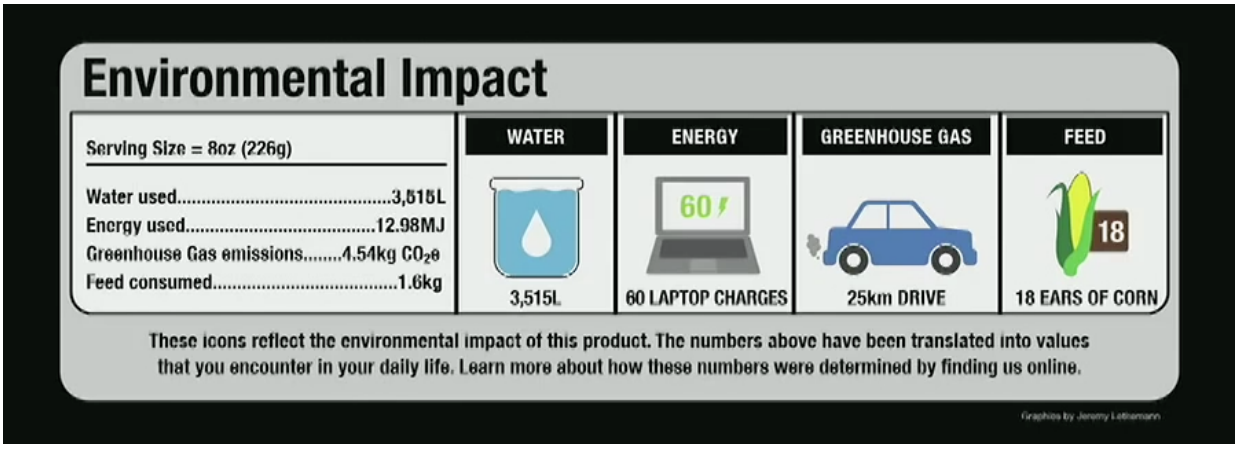
Yet this begs the question: should these companies still voluntarily go through FDA's safety regulation? More so, how could these companies address consumer safety concerns if they bypassed the FDA? Nearly all the cell ag startups pride themselves in being transparent with the public, so it would be surprising if they choose not to voluntarily show that their products are safe.

PUBLIC PERCEPTION

No matter how safe or sustainable cellular agriculture may make animal products, or how many regulations are put to ensure the product's safety, it ultimately comes down to consumers and the public to accept cellular agriculture. As with most novel technologies, time will tell to see how the public perceives and accepts this new category of sustainable goods

A lot of actors in the field are trying to promote cellular agriculture by being as transparent as possible about the science, the manufacturing process, and the positive environmental implications. Research has shown that when taught about the sustainability aspect of cell ag in comparison to conventional animal products, people view it more positively and are interested in trying it. Using *quantitative* labels on animal products could help show the environmental impact of conventional animal products when compared to cellular agriculture ones. This would be more effective than *qualitative* labels, which requires prior knowledge of those labels to understand them.

Beyond public understanding, there are questions about cultural acceptance that still need to be addressed. For the world's Jewish and Muslim populations, it is yet to be determined whether cell-based meat can be labelled as kosher or halal, respectively. It will be important for all actors in the field to fully address this and any other questions or concerns that emerge as cell ag products enter the market.



Quantitative Labelling. Photo taken from TedX presentation by Isha Datar: Rethinking Meat at TedxToronto, 2013

SOCIO-POLITICS AND MARKET COMPETITION

A key challenge that cellular agriculture (and all innovative technologies) has to face is the socioeconomic impact of what their technology may cause. In the United States, over 1.6 million people are employed by the livestock industry, which makes up about 22% ($31.8 billion) of all income from agricultural exports. If cellular agriculture successfully enters the market and one day becomes large enough to disrupt the livestock industry, what would happen to all the people involved in the livestock industry? While this isn't a question that cell ag companies would necessarily be asking, it is an important political question that may have severe implications.

In order for cell ag to be successful and widespread, there will need to be political support—either in the form of positive policies or a lack of negative targeting policies. Will politicians and governments embrace the new technology, or will they feel threatened by it? It is important to balance the needs of one's constituents and citizens with the needs for a sustainable food system that provides enough to feed the world by 2050.

Only time will ultimately tell what happens.

One group that may feel threatened by a rise in cellular agriculture would be the incumbent meat and dairy corporations. There have been investments by large meat producers like Tyson Foods, Cargill, and European poultry giant PHW that suggest some companies may be interested in cultured meat technology.

This doesn't mean that the whole industry is ready to accept cellular agriculture. Particularly when it threatens their market shares.

In February 2018, the United States Cattlemen's Association petitioned the USDA to narrow the definition of meat to exclude anything that does not come from a slaughtered animal. Following that, the National Cattlemen's Beef Association called for the USDA to exclusively regulate the field in hope that they would be more favorable to meat incumbents.

Will other companies and groups use their means and power to prevent a successful cell ag launch? Or will cellular agriculture likely be too small for many corporations to even be concerned about initially?

CONCLUSION

In May 2018, the state of Missouri passed a law that banned plant-based and cell ag companies from using the word *meat* or any meat-derived terms to describe their products. The law came into effect on August 28, 2018. And so did the fight for the word meat.

The Good Food Institute, the non-profit supporting the commercialization of both plant-based and cell-based meats, sued the state of Missouri to stop the law. The case will impact whether other states could Missouri's lead and also pass regulations over the definition of meat.

There are clearly many obstacles for cellular agriculture to overcome. It is important to note that not all of them have to be passed before cell ag hits the market. Some challenges are more long-term obstacles that cell ag will eventually have to face.

Perfect Day Foods and Clara Foods will likely find it easier to enter the market. They may be among the first food products to enter and set the precedent for how the market will respond to cell ag products. If Just is successful in launching the first cell-based meat this year, they will also play a role in how the public views the field as more companies enter the market at a later date.

Closing Thoughts

The first lab-grown beef burger cost $330,000 to produce in 2013; by the end of 2017, the price fell below $12 for each cell-based beef burger. The field is *clearly* moving forward.

The rise of new startups in the field as well as constant investments pouring into the field are a great sign of what is to come.

Yet the field is still in its early stages. Besides a few of them, most products are still in development. It will likely stay this way until the companies learn to overcome some of the obstacles ahead, particularly scaling production.

Until then, we can only wait to see what happens next in the field!

In a short few years, cellular agriculture has grown from a theory to the lab.

Cellular agriculture is no longer an idea.

It *can* be done. It *can* become the future of food.

Thank you for taking the time to read an Introduction to Cellular Agriculture!

We would love to hear back from you on the book – comments, thoughts, suggestions, everything!

You can leave your comments on the CellAgri website, or you can tag CellAgri in your feedback on Twitter (@cellagritech) or Instagram (@cellagri).

If you have any questions or comments, please feel free to email me at Ahmed@cell.ag.

You can keep up-to-date with the future of food by subscribing to CellAgri's weekly newsletter. We keep you posted with the latest news and insights coming out of the field changing food forever.

Appendix

The Companies in Cellular Agriculture

An overview of all the companies and non-profits that are using cellular agriculture to change the future of food.

Aleph Farms

Location: Tel Aviv, Israel

Focus: Meat

Founders: Didier Toubia and Shulamit Levenberg

Website: www.aleph-farms.com

BlueNalu

Location: San Diego, California

Focus: Seafood

Founders: Lou Cooperhouse, Chris Dammann, and Chris Somogyi

Website: www.bluenalu.com

Bolt Threads

Location: San Francisco, California

Focus: Clothing (Spider silk, leather)

Founders: Dan Widmaier, David Breslauer, and Ethan Mirsk

Website: www.boltthreads.com

Cellular Agriculture Society

Location: Cambridge, Massachusetts

Focus: Non-profit

Founder: Kristopher Gasteratos

Website: www.cellag.org

Clara Foods

Location: San Francisco, California

Focus: Egg white

Founders: Arturo Elizondo, David Anchel, Isha Datar

Website: www.clarafoods.com

Finless Foods

Location: San Francisco, California

Focus: Fish

Founders: Mike Selden and Brian Wyrwas

Website: www.finlessfoods.com

Future Meat Technologies

Location: Jerusalem, Israel

Focus: Meat

Founders: Yaakov Nahmias and Rom Kshu

Website: www.future-meat.com/

Geltor

Location: San Francisco, California

Focus: Collagen (gelatin, cosmetics)

Founders: Alex Lorestani and Nick Ouzounov

Website: www.geltor.com

Good Food Institute

Location: Washington, D.C.

Focus: Non-profit

Founder: Bruce Friedrich

Website: www.gfi.org

Higher Steaks

Location: London, United Kingdom

Focus: Meat

Founders: Benjamina Bollag, Stephanie Wallis, and David Hay

Website: www.highersteaks.com

Integriculture

Location: Tokyo, Japan

Focus: Meat

Founder: Yuki Hanyu

Website: www.integriculture.jp

Just (formerly Hampton Creek)

Location: San Francisco, California

Focus: Meat, plant-based egg products

Founders: Josh Tetrick and Josh Balk

Website: www.justforall.com

Meatable

Location: Leiden, Netherlands

Focus: Meat

Founders: Krijn de Nood, Daan Luining, and Ruud Out

Website: www.meatable.com

Memphis Meats

Location: San Francisco, California

Focus: Meat

Founders: Uma Valeti and Nicholas Genovese

Website: www.memphismeats.com/

Mission Barns

Location: San Francisco, California

Focus: Meat

Founders: Eitan Fischer and David Bowman

Website: www.missionbarns.com

Modern Meadow

Location: New York, New York

Focus: Leather

Founder: Andras Forgacs

Website: www.modernmeadow.com

Mosa Meat

Location: Maastricht, Netherlands

Focus: Meat

Founders: Peter Verstrate and Mark Post

Website: www.mosameat.eu

New Age Meats

Location: San Francisco, California

Focus: Meat

Founders: Brian Spears and Andra Necula

Website: www.newagemeats.com

New Harvest

Location: New York, New York

Focus: Non-profit

Founder: Jason Matheny

Website: www.new-harvest.org

Perfect Day Foods

Location: San Francisco, California

Focus: Milk

Founders: Ryan Pandya, Perumal Gandhi, Isha Datar

Website: www.perfectdayfoods.com

Shiok Meats

Location: Singapore

Focus: Seafood

Founders: Sandhya Sriram and Ka Yi Ling

Website: www.shiokmeats.com/

SuperMeat

Location: Tel Aviv, Israel

Focus: Meat

Founders: Ido Savir, Koby Barak and Shir Friedman

Website: www.supermeat.com

Wild Earth

Location: San Francisco, California

Focus: Pet food

Founders: Ryan Bethencourt, Ron Shigeta, Kristin Wuhrman, and Abril Estrada

Website: www.wildearth.com

Wild Type

Location: San Francisco, California

Focus: Fish

Founders: Justin Kolbeck, Arye Elfenheim

Website: www.thewildtype.com

Additional Resources

Resources on Cells, Cell Division, and Stem Cells

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