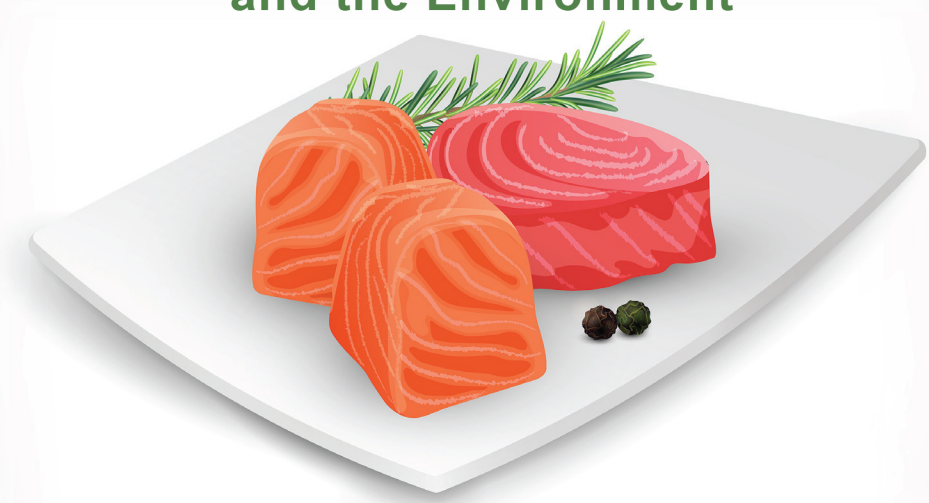
CULTIVATED MEAT TO SECURE OUR FUTURE

Hope for Animals, Food Security, and the Environment



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A NEW HARVEST—A NEW WORLD

Isha Datar

From Hunt to Harvest

No one knows why agriculture arose.[1]

Some say it was climate change, others say it was resource scarcity. Surely it was at least both. This was around 10,000 BCE, the end of the last Ice Age. Glaciers were melting, sea levels were rising, and ecosystems were radically shifting around the planet. It was a dynamic time and adaptability was a matter of life and death. Agriculture was emerging independently around the globe; it made the food supply more reliable than hunting alone. It was a source of abundance.

While the causes of the transition from hunting to agriculture are unclear, the effects are undeniable: domestication fundamentally changed life on Earth.

In the millennia following the advent of agriculture, the human lifestyle transformed from small, nomadic groups to larger, denser societies anchored in villages and towns. With the emergence of societies came deep class divisions, gender inequality, malnutrition, infectious disease, and an ever-present risk of starvation through crop failure. These caused some scholars to interrogate rather than celebrate the idea that life in agriculture-enabled society was better than life in the hunter-gatherer communities that preceded it. The advent of agriculture codified the relationship between food and power and has shaped the outcome of wars, nations, and communities ever since.

This was a pivotal shift in the relationship between human and nonhuman life on Earth. I find the transition from killing wild animals

to mass producing and slaughtering domesticated ones to be the most profound change. It altered our relationship with sentient life. No longer were animals free until they were food. Instead, they were born into oppression with their fates sealed. We began to own land and living things.

Domestication, by definition, is the process of adapting living things for human use. Consequently, the oppression of animals and humans goes hand in hand. That agriculture provoked gross social inequality and war should be no surprise.

Agriculture's primary effect was a rapid increase in the human population. The secondary effect was society.

While there is no scholarly consensus on why agriculture arose, my nonscientific, non–peer reviewed opinion is that at this point we chose to put humanity first. It was a decision for the population, not for the individual. Not just allegiance within small bands of hunters and gatherers, but a choice to create abundance for our species, enabled by technology.

The question is, have we achieved abundance that will last us into the future? Or are we more fragile now than ever with modern agriculture?

Biological Limits—Logical Ends

We normally look at the hunting-to-harvest transition in the context of humanity, but this pivotal shift in the relationship between human and nonhuman life affected all living things on Earth.

Twelve thousand years into the era of domestication, animal agriculture particularly has had an outsized effect on every level of biology, from the organism to the biosphere. It is especially in the last century, with the invention of the factory farm and technology-enabled intensification, that I feel we have not only changed biology on Earth, but also reached biological limits. To me, animal agriculture has reached its logical end.

Let me explain.

At the level of the organism—look at what has happened to chickens within fifty years of selective breeding. By simply picking which birds to breed with one another, chickens became "broilers," a human invention

optimized for meat production. An undomesticated chicken can live for four to seven years. Broilers grow meat so fast that they must be slaughtered within four to seven weeks of being born, because their legs cannot hold up their bodies.

Image showing a commercial broiler genotype produced in the 1950s (left) and a commercial broiler genotype produced in 2005 (right). Both birds are the same age (fifty-six days) and have been fed on an identical modern diet; they weigh 905 and 4,202g, respectively: https://link.springer.com/content/pdf/10.1007/s13593-016-0398-2.pdf

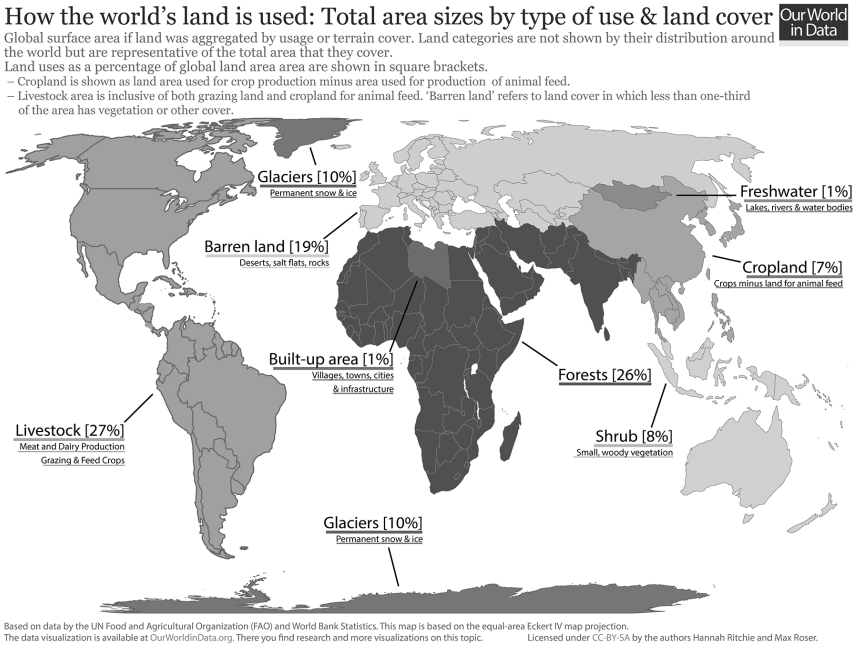
It is hard to envision how much more we could modify this animal's body to make it a more efficient meat-making machine. We have gone beyond the biological limits of this organism. We have maxed out this animal.

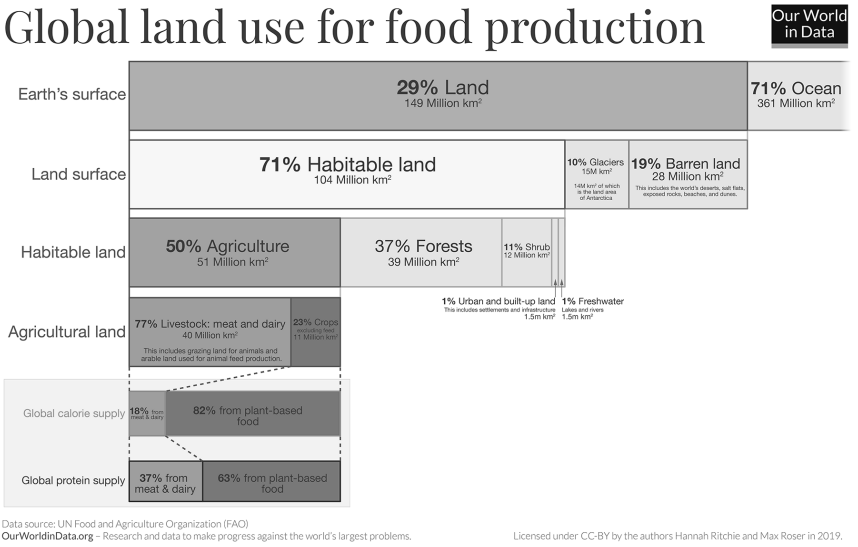
Now let us look at the dense population levels in which animals are kept. Today, farm animals in concentrated animal feeding operations (CAFO)[2] are packed together in such small spaces that the risk of epidemic viral outbreaks is at an all-time high. The cull of millions of chickens to contain avian flu is a common, yearly phenomenon.[3] The next outbreak is always a matter of when, not if. But the biggest one to date isn't avian.

We are in the midst of an unprecedented pandemic, unlike anything we have ever seen before. I am not talking about COVID-19. I am talking about African Swine Fever, the biggest pandemic you have never heard of because it just so happens to affect pigs and not humans. Since 2018, this deadly virus has already killed one in four pigs on Earth.

By my calculations this is more pig deaths in a single pandemic than all human deaths in the worst pandemics in human history combined. That means hundreds of millions of pigs, completely lost from the food supply. Our farmed animal populations are so high and so dense that they actually threaten food security. We have maxed out entire species.

Now let's zoom way, way, out, and look at the surface of our planet. We dedicate more of our world to feeding cows, pigs, and chickens than to anything else. Almost a third of all land on Earth—about 27 percent—roughly equivalent to all of North and South America combined, is used to fuel our desire for meat, milk, and eggs.[4]





By contrast, we use only 7 percent of the planet to grow everything else. Combine this with the fact that all the land for livestock produces only a quarter of the calories that all of cropland produces. It is easy to see that we are drastically overdependent on animals as a food production system.

What about the climate? Every year, the global livestock population produces 7.1 gigatons of CO_2 equivalents representing 14.5 percent of all human-made greenhouse gas emissions.[5] Our global herd is one of the biggest drivers and victims of climate change. A whopping 44 percent of animal agriculture's emissions are methane. On a hundred-year timeline, methane's global warming potential (GWP) is twenty-eight times that of CO_2. Upon release into the atmosphere, methane's GWP is about eighty-four times that of CO_2 over a twenty-year period.[6] If we look just at cows—which alone produce 9 percent of all greenhouse gas emissions—we see a population especially prone to climate risk because they are still farmed outside. In a warming climate, cows become less efficient at producing meat and milk.[7] However, more catastrophic are the extreme weather events—heat waves, storms, floods, and fires—that see tens of thousands of cattle wiped out overnight.

That the mass production of cows is driving mass destruction of cows is an ironic tragedy speaking to the absurdity of the situation that we are in. In a changing climate, animal agriculture is simply not a climate-friendly nor climate-ready means to feed the world.

When viewed through the adage that we are only nine meals away from anarchy, civilization built upon the foundations of agriculture has put itself at existential risk. It does not take long for food insecurity to lead to societal collapse.

At every organizational level of life, animal agriculture stands on the brink of a painful self-correction. Animal agriculture has pushed us beyond the limits of biology, to the point of actually threatening life on Earth. The status quo has us on a short runway to environmental and societal collapse. Where do we go from here?

Here are the parameters:

A ravaged planet. A rapidly changing climate. A food system that is not so much a "system" as it is a tightwire, a supply chain, five species wide.[8] The weight of global food security precariously resting upon it.

Domesticating animals helped us get from the end of the last Ice Age to nearly eight billion people on planet Earth today.[9] How would you feed the world for the next ten thousand years?

I would focus on the biggest problem: the one that uses the most land, feeds the fewest mouths, and is the most prone to viral outbreaks and climate disasters.

I would change animal agriculture. And instead of farming animals, I'd farm cells for food.

A New Harvest

Cellular agriculture is the production of agricultural goods from cell cultures rather than from whole plants or animals.

For more than a decade, I have been an advocate for growing animal products like meat, milk, and eggs in a laboratory. In recent years, I have been able to taste a number of prototypes: meatballs, sausages, nuggets,

burgers, sashimi, meringues, ice cream, cheese, and milk. All have been made without the need for animal husbandry, artificial insemination, confinement, or slaughter.

These foods made from cells instead of animals are not just the latest take on a veggie burger or a new fad in food innovation. Cellular agriculture is our ticket to a new food system; and if we want it, a new world.

Cellular agriculture is a new field by name[10] but an old idea. While there have been earlier mentions of the concept, a well-known quote among proponents of cellular agriculture is from Winston Churchill's 1931 essay in *Strand Magazine*:[11] "We shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium."

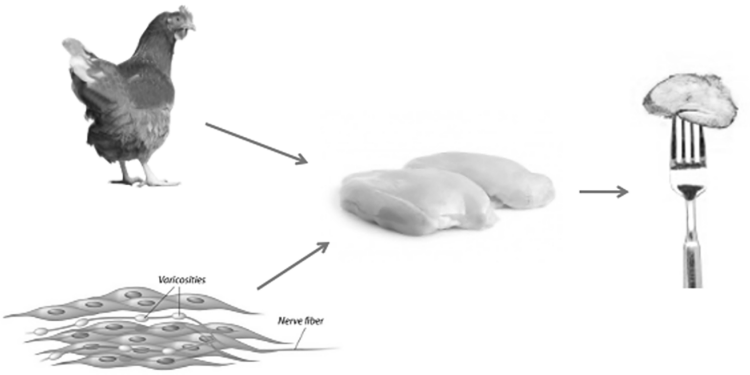
Churchill is describing the first of the two main approaches in cellular agriculture when you are developing products made of cells. Take the example of chicken: rather than raise whole chickens with beaks, feathers, and sentience, we grow the meat directly from muscle cells.

First, a biopsy is taken from the animal, and the cells of interest are extracted. If we were seeking to create lean chicken breast, we would be most interested in muscle cells. But we could also select fat cells or the cells that create connective tissue, too, to confer different taste and textural properties to the meat we are going to grow.

Second, muscle cells particularly love to attach on a surface, so we might provide a material for the cells to attach to. This is called a scaffold, likely made of some kind of inert, plant-based material. The scaffold helps cells fuse and elongate, becoming the long muscle fibers we see in meat.

Then of course we need to feed the cells so they can grow and divide. Cells grow in a liquid medium which provides everything they need: amino acids, fats, carbohydrates, growth factors, and more.

Last, all of this growth—the cells, on the scaffolds, in the media—happens within bioreactors. These are large stainless steel tanks that look a lot like brewing equipment. Bioreactors simulate a body by providing a controlled environment where temperature, oxygenation, and various other inputs and outputs can be controlled and closely monitored. At the end you could have a mass of chicken cells and tissue that could become a nugget that was boneless and skinless and all white meat right from the start.

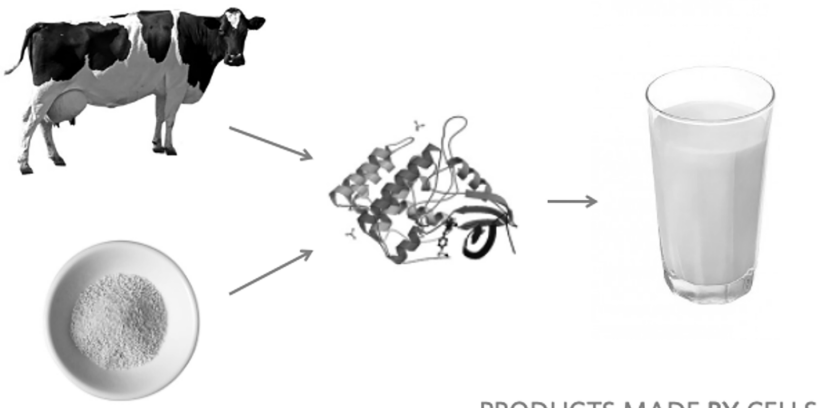


PRODUCTS MADE OF CELLS

The second main approach in cellular agriculture is developing products made by cells. In this case, the product is one or more organic molecules—like proteins, fats, or enzymes. To create these, we can reprogram microorganisms to churn out what we're looking for. Let's take the example of dairy proteins. The gene sequences for dairy proteins are sourced online in an open source database called UniProt. The genes are then printed onto a strand of DNA, then inserted into the DNA of a microorganism. This microbe is now engineered to make milk proteins for us. Think of it as brewing when you feed sugar to yeast in a big stainless steel fermenter. But instead of that yeast making alcohol, it is an engineered microbe turning sugar into dairy proteins for yogurt, cream cheese, and ice cream.

By engineering biology, we could really grow anything that might come from a plant, animal, or cells instead. Egg whites wouldn't always have to come with a yolk. Leather and silk wouldn't have to come from the back of an animal or the home of a silkworm. Foie gras could be completely cruelty-free. Vanilla would no longer need to be rainforest farmed. Chocolate would not have to rely on child labor, trafficking, or slavery.

We already use cellular agriculture products in our everyday lives, just in super small quantities. Several vitamins, flavors, and enzymes are already made from cells. The first animal product replaced by a cell-cultured version was insulin, a small protein used to treat diabetes.



In food, the first animal product replaced by a cell-cultured version was rennet, the enzymes used in cheesemaking.

Rennet, the enzymes used to make curds and whey from milk, was once made from the stomach lining of baby calves. A cell-cultured version of the key enzyme, chymosin, was approved for the market in 1990. Today, only some thirty years later, more than 90 percent of rennet used in cheesemaking comes from an engineered microbe in a bioreactor instead of from a newly slaughtered calf.

Imagine if we could tell a similar story for meat, milk, and eggs. Cellular agriculture wouldn't just be better for chickens, cows, and pigs. It could be better for the planet and all of its inhabitants.

For instance: Estimates of cultured meat's potential show that compared to conventional beef cultured meat has the potential to reduce climate change impacts by up to 80 percent. This impact potential exists across the usage of land, reduction of greenhouse gas emissions, and utilization of water.[12] While these estimates are early and very likely to change with further research and development, there is no doubt of the potential that cellular agriculture holds.

This isn't a new product—this is a new paradigm: cellular agriculture is a brand-new toolset for producing food. It is our once-in-a-lifetime opportunity to get a second chance at agriculture.

A New World

Imagine a world where the factory farm looks more like a factory and less like a farm. Picture breweries, with their stainless-steel tanks, housing biological processes that transform ingredients into foods—but instead of beer, milk, meat, or egg, proteins are inside. The equipment feels crafted and artisanal because it is. Cellular agriculture is introducing the next era of domestication (the domestication of the cell). It is also introducing an entirely new way of thinking about and interacting with food and how it is made.

The most compelling promise of cellular agriculture is the ability to create identical animal products without the compromise or willful ignorance of its origin story. If we were presented with two burgers, or two steaks, that gave you an identical experience as an eater, but had wildly different origin stories—which would you choose? We could perpetuate deeply embedded food cultures and culinary traditions—and we could create new ones, too.

We haven't seen a transformative culinary tool like this since biotechnology was invented with the discovery of fermentation. Before we fermented foods, we would never have thought about making milk hard, and stinky, and melty, and stretchy—turning it into cheese and the hundreds of varieties of cheese we have today. When we begin to grow foods from cells, meat no longer needs to be defined by an animal's body. Cell cultures could grow in thin, translucent sheets, or thick liquid slurries. Cellular agriculture is a new tool for culinary creativity and the opportunities are beyond what we can even conceive of today.

One example of this potential future is that of "The Carnery" from the *In Vitro Meat Cookbook*:

> Counter Culture, London's latest *in vitro* micro-carnery, proves it's the real thing. The restored 1970s-era English brewpub boasts an expansive bar of reclaimed mahogany and booths upholstered with magnificent in vitro leather. Steaks are grown to precision inside giant steel vats decorated (functionally) with illuminated green algae tanks. A disorienting mingling of global spices flavors varieties of exotic and heritage meats like boar and Berkshire, all of which

> are cultured on site. The large charcuterie board with mushroom-medium duck foie gras, coriander mortadella, and crispy lobes of sweetbread, pairs perfectly with a shortlist of probiotic cocktails (try the rum and kombucha).[13]

What about our relationship with animals? Since the dawn of domestication we have imposed our goals and controls on living beings at the expense of animals' health and welfare. But it has been at the expense of human health and welfare too.

Working in a factory farm or a slaughterhouse is some of the worst work one can be tasked with. It's no wonder that turnover rates for workers in slaughterhouses and meat processing often exceeds 100 percent annually[14] and that these roles are often filled by individuals with few other choices. How many meat eaters have ever slaughtered or even butchered their own animals? The disconnect between consuming and producing animal products is wider than it has ever been.

Meat eaters continue to abstract the animal from the animal product. Most consumers desire boneless, skinless, fat-trimmed chicken breast, with as little resemblance to or reminder of the body it came from as possible. I am not convinced that we eat meat because it comes from animals' bodies; I believe we eat meat despite its origins. So why not fully abstract the animal and produce meat directly without a body at all?

By growing meat in a lab, we could fundamentally change humanity's relationship with sentient life, because we would no longer have to kill animals to survive. To me, that doesn't just change how we think about cows, pigs, and chickens. To me that ignites a new respect for life on Earth, all earthlings, and our inherent interconnectedness.

What about our relationship to the Earth? Remember how I shared that cell cultured meat would require 99 percent less land than beef? Of course: ranching can't go vertical, but cell culture can. By transitioning to cellular agriculture, if we could alleviate half—even a quarter—of the land we dedicate to livestock today while still meeting the global demand for protein, imagine what we could do with the rest.

Suddenly, it becomes possible to choose to do things like reviving the Amazon Rainforest, which we continue to clear-cut for cattle. Or re-diversifying other ecosystems that have been colonized by cows, corn, and soy. Or returning stolen lands to indigenous peoples, who have a much longer track record of successful land and resource management. If we are wise, we can reintroduce more restorative, regional approaches to agriculture. These are the kind of approaches that get rejected for low yields because those who are measuring aren't measuring everything that matters.

The United Nations estimates that we will have to restore natural ecosystems on land the size of China if we are to tackle climate change. Cellular agriculture actually puts this on the table. Not only could we free up land for restoration, we could also make the products we know and love at a fraction of the emissions.

We could reduce the risk of epidemic viruses and avoid antibiotic resistance. We could produce food locally, closer to the consumer. We could perpetuate food cultures and culinary traditions—and we could create new ones, too. We could change our relationship with sentient life. We could achieve food security in a climate-changed world.

What stands in our way?

Two things stand in our way. The first is developing the technology.

For cellular agriculture to realize even a portion of what we hope, we need the science to work. We have been modifying microbes to make proteins for decades, so that approach is a lot nearer term. But growing animal cells and tissues like meat is science that is much newer and much more challenging. Animal cells are just more finicky than microbes, and growing a lot of animal cells and achieving three dimensionality is no easy feat.

It's tough science. But we're getting there. Back in 2013, it cost more than €250,000 to make a single cell-cultured hamburger. Today, we are seeing prices come down rapidly. Cultured meat is now $50 per pound, one twenty-seven-thousandth of what it was less than a decade ago. No, that price is not competitive yet. But I can only see the price of cultured

meat coming down with new breakthroughs and advances. I can only see the price of meat from animals going up.

The price of meat today is already artificially low due to heavy subsidization, and meat prices do not account for costs to the environment or public health. As we enter a world changed by COVID-19, African Swine fever, and the climate, the price of meat has to increase. If a start-up pitch deck on the meat industry were created today—government subsidized, prone to catastrophic risk, dependency on undocumented workers, 100 percent rate of workforce turnover—no investor would fund it.

Price parity would be even more so within reach if cellular agriculture were on an even playing field. On one side we have animal agriculture, heavily supported by government and public funding. On the other, we have an emerging field, with intensive research and development and enormous potential for public good, which is left solely to the private sector and market forces.

Now here's what you might be thinking: "This is awesome, sign me up, I'm ready for lab-grown meat to unlock a new era of agriculture." Or you might be thinking: "This all sounds nice, but is this really going to change agriculture? Or is it simply going to perpetuate what got us here? Isn't this just further industrialization, globalization, consolidation?"

And my answer to that is: "Yes, you're right." None of the benefits of cellular agriculture can be realized if we rely on technology and market forces alone. Fulfilling the promises of this technology is going to take boldness and creativity outside of the lab, too.

Technologies do spearhead massive change. But it's *how* that technology is developed, governed, owned, and implemented in society that will dictate the impact that it actually has on the world. We have a lot of deeply established structures, norms, and understandings that constrain radical change and stand in the way of our realizing this life-sustaining world. We don't just need to create a new world; we need to transform an old one.

This act of creative destruction doesn't happen often in the reality of technology and business. No matter how much the word "disruptive" gets used to describe new inventions, it is often the case that the old system remains with a new coat of paint. Innovation is bolted on as to not too drastically change the balance of power and to attract capital. When the capital for an industry is concentrated in a few key players, those same players tend to be incapable of creating this necessary destruction and rebirth. Much like how Silicon Valley historically owes its existence to the focused need of the US government for chips and computing, food may require the same type of focused intervention.[15]

The promise of cellular agriculture is the same as the promise of agriculture twelve thousand years ago: to create abundance for our species, enabled by technology. While I don't have all the answers for how to move cellular agriculture forward to truly realize this promise, I do have one suggestion. We must use the disruptive potential of cellular agriculture to rethink everything that needs rethinking so we can truly create an abundant, life-sustaining world for all.

"We are as gods, we might as well get good at it."—Stewart Brand[16]

Author Biography

Isha Datar is the executive director of New Harvest, a nonprofit dedicated to ending our dependence on industrial livestock production by growing foods like meat, milk, and eggs from cells instead of animals. After publishing one of the first papers to discuss cultured meat in academic literature, she coined the term "cellular agriculture" to create a new category for agricultural products produced from cell cultures rather than whole plants and animals.

In 2014, Datar co-founded two of the world's first cellular agriculture companies: Perfect Day (formerly Muufri) and The Every Company (formerly Clara Foods). She promptly donated all of her founding equity to New Harvest to establish a public endowment for cell ag research. Now, she works to accelerate scientific breakthroughs and steward cultured meat such that it serves the public good.

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