

Battle for the dinner table:
Can vegan analogues curb America's reliance on meat?

by
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ABSTRACT

As demand for meat continues to rise, globally, the livestock industry produces an estimated 14.5% of manmade greenhouse gas emissions — more than two-thirds of which come from cattle. Meat production requires roughly three-fourths of the world's agricultural land and heavy crop and water usage, which according to scientists is a threat to biodiversity, and an accelerator of deforestation and food insecurity. Plant-based diets represent an opportunity for a more sustainable food system, according to large international scientific reports published by organizations including the United Nations Intergovernmental Panel on Climate Change and the EAT-Lancet Commission.

A practical solution seemingly exists: a new generation of plant-based meats which are designed to look, cook, taste, and smell just like meat with a much smaller environmental footprint. In 2016, Beyond Meat and Impossible Foods began selling their meatless burgers, and quickly became leaders in a growing field of companies offering realistic plant-based meat analogues. In the United States, where more meat is consumed per person than anywhere else in the world, consumer acceptance of the novel vegan meats has so far been mixed. Researchers know that taste is highly psychological, and that many people prefer foods they are familiar with. The plant-based meat industry faces a challenge of scaling up to offer a product as appealing, accessible, and inexpensive as meat, which is a cornerstone of many peoples' diets — and often a source of great comfort and pleasure.

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Kimberly Sayer, with a laugh, says she eats “frankenfoods” several times per week.

Sayer, who is in her fifties and works in social services, grew up eating beef raised at her childhood home, a small farm in Washington. When she moved away as a young adult, she realized “that not every cow grows up in my backyard.” She was horrified to learn about conditions in the large factory farming operations which produce much of the United States’ meat.

She also became increasingly aware of meat’s negative effects on the environment.¹ The livestock industry produces approximately 14.5% of manmade greenhouse gas emissions, which trap heat in the atmosphere and contribute to climate change. Cattle are responsible for about two-thirds of that 14.5%.²

Sayer says she could no longer enjoy eating meat. The “texture, and the flavor, and the mouthfeel, it was all starting to feel weird to me,” she says. About five years ago, Sayer and her husband eliminated beef from their diets, then pork, and then chicken. Now — aside from the occasional piece of fish — they are part of the roughly 8% of Americans who identify as vegan or vegetarian.³

Around the same time the Sayers stopped eating beef, two companies were gaining a lot of attention for developing a new class of vegan meat replacements. Where previous generations of meatless products were mostly geared toward vegetarians or vegans, plant-based burgers from Impossible Foods and Beyond Meat were designed to taste, smell, cook, and look just like meat — and to appeal to its biggest fans.

It’s these hyper-realistic products that Sayer has lovingly dubbed “frankenfoods,” a term she borrowed from a source she can’t remember. She classifies a frankenfood as “anything that the purists complain is full of chemicals: Beyond burgers, fake chicken nuggets, pretty much any meat replacement that’s not like a straight-up vegetable. If I could do it in my kitchen, it’s probably not frankenfood.”

Sayer says she was eager to try frankenfoods as soon as she heard of them. The rollout was slow, and she recalls “patiently waiting” for the products to come to a restaurant or store near her small town in Washington. When they finally did, she liked them even more than she expected. Now, she uses frankenfoods in some of her favorite recipes, like shepherd’s pie.

Yet Sayer remains an outlier. On average, Americans are eating more and more meat. The US Department of Agriculture estimates that in 2018, there was enough meat produced for every American to eat more than 220 pounds — an all-time high.⁴ In 2016, Americans ate more meat

per capita than people anywhere else in the world.⁵ For many Americans, meat remains an affordable, filling, and accessible food choice.

The trend isn't limited to the United States. Globally, the human population has roughly doubled in the last 50 years, while annual meat production has about tripled.^{6, 7, 8} But consumption isn't evenly distributed. Per capita meat intake is much higher in the United States, parts of Europe, and Australia than in most other parts of the world, according to Jessica Fanzo, professor of global food policy and ethics at Johns Hopkins University. Fanzo says "the trends show that demand for meat is going to keep rising" around the world, particularly in nations with growing economies.⁹

Raising animals to produce all that meat requires a lot of resources. About 75% of the world's agricultural land is used for raising and feeding livestock, and almost 40% of the world's calories from crops are used for animal feed.¹⁰ Because of how resource intensive meat production is, if current consumption patterns continue, Fanzo says, there will be "significant land use constraints, more deforestation, and irreversible biodiversity loss."

In 2019, Fanzo was part of a group of 37 scientists from 16 countries who wrote the EAT-Lancet Report, which aimed to determine what a more equitable food system designed to optimize both human and environmental health would look like.¹¹ The committee suggested that by 2050, to feed the globe's predicted population of 10 billion, global red meat consumption should be at 50% of its current level. In its place, the committee recommends fruits, vegetables, nuts, legumes, and other items that require less water, land, and greenhouse gas production.^{12, 13} While some questioned the feasibility and specificity of the committee's recommendations, the report is one of many calling for a reduction in greenhouse-gas intensive meat production.¹⁴ The same year, a special report from the United Nations' Intergovernmental Panel on Climate Change, assembled by more than 100 experts from around the world, asserted that relying on plant-based and some sustainably sourced animal products could greatly improve both human and environmental health.^{15, 16}

A 2019 University of Michigan report commissioned by Beyond Meat confirmed that when compared to a same-sized beef patty, a Beyond burger produces 90% fewer greenhouse gas emissions, and making one requires 99% less water, 93% less land, and 46% less energy.¹⁷ Bill Gates, an investor in both Beyond Meat and Impossible Foods, told MIT Technology Review in early 2021 that wealthy nations should switch entirely to "synthetic beef" to curb climate disaster.¹⁸

It seems intuitive that the advent of a tasty and realistic meat alternative would at least put a dent in massive slaughter operations. But five years after the release of Beyond and Impossible, Gates

acknowledges that the novel vegan meat substitutes account for less than 1% of the world's "meat." Still, he believes the products are "on their way" to taking more market share.¹⁹

For those who consume that small percentage, plant-based meats have transformed their diets. With the help of Frankenfoods, Sayer has been able to stick to a vegetarian lifestyle that satisfies both her cravings for meat and her desire to protect animals and the environment. Though Sayer is happy she made the transition to novel vegan meats, she acknowledges that many of the products are far pricier than animal meat, so she consumes them less frequently. A pound of Beyond plant-based ground meat — Sayer says she and her husband go through three or four pounds per month — can cost \$8-\$10, about double the price of ground beef.

They're harder to find, too. The closest grocery store that carries the vegan meats is more than a 30-minute drive from Sayer's home. She does a lot of cross-state travel for work, so it's not too inconvenient for her, but she knows it could be for others. Sayer used to go to her local Burger King several times a week for their Impossible breakfast sandwich, but she found out recently that they've stopped carrying it.

And, she says, her "Frankenfoods" do taste slightly different from meat. That's a plus for her, since she now dislikes animal products. But for an avid meat eater, it likely isn't.

While 55% of Americans say they are willing to eat more plant-based meat alternatives, getting them to consistently choose plant-based products over meat is not as simple as just engineering a replacement.²⁰

"There's three things that consumers buy food on: taste, price, convenience," says David Donnan, an adjunct associate professor at Northwestern University's Institute for Sustainability and Energy with expertise in agriculture and food. While the novel vegan meats have made impressive strides in their ability to copy animal meat, which should improve their marketability, Donnan says, most still fall short on at least one of those three areas.²¹

To cut prices and expand accessibility, the companies producing these products must scale up operations — a process that generally necessitates high consumer demand, which is itself unlikely until the products become less expensive and more accessible.

New technologies and products often face challenges to gaining consumer acceptance. But the vegan meat industry faces an additional hurdle: its foods are directly competing with products that bring sensory and psychological comfort, products that many Americans invite to the dinner table every evening.

The United States has been a meat-eating nation from its earliest days, likely a vestige of its British roots. Since at least the 1700s, meat, particularly beef, has been a central part of British self-understanding, says Harriet Ritvo, a scholar of British and environmental history at MIT.²² Beef's rise in British culture coincided with the 18th century agricultural revolution, a time when food production in the country soared amid new crop technologies and animal breeding techniques.²³

Yet meat remained a delicacy that was out of reach for many lower and middle-class Brits, Ritvo says. Some headed for North America eager to have their own land, where they could breed and raise their own livestock, many of which were imported from Europe. Meat and land, once a luxury to so many Europeans, seemed abundant in the colonies.

Still, the American quest for a pre-packaged commercial substitute for meat is a surprisingly old one.

In 1896, John Harvey Kellogg, a doctor, nutritionist, eventual cereal pioneer, (and, it should be noted, a vocal eugenicist), devised Nuttose, a peanut and wheat-based commercial product that was billed the "perfect substitute for flesh food."^{24, 25} Ads for the product, like one that ran in an 1898 Montana newspaper, claimed that Nuttose "resembles meat so closely as to be called vegetable meat."²⁶ Like meat, it was solid, high in protein, and easily transported and served.

Kellogg was a member of the Seventh Day Adventist Church, a religious group whose members largely avoid meat. At the turn of the 20th century, Loma Linda, an Adventist food company, began selling plant-based proteins. Throughout the 1900s, they developed faux chicken, hot dogs, burgers, and even "Tuno."²⁷ The foods weren't designed to tempt ravenous meat eaters to adopt a plant-based diet. Rather, they were meant to provide already-vegetarian Adventists with protein-packed, meatless meals.

Per person meat intake rose in the United States throughout the 1900s, with beef consumption peaking around 1980.²⁸ By the end of the 1980s, concerns about the high levels of saturated fat and cholesterol in red meat led to increased demand for poultry and leaner meat.²⁹

The shift away from beef may have benefitted the veggie-friendly restaurateurs of the 70s and 80s. In 1982, Californian Gregory Sams created the first commercially available vegetable burger, the VegeBurger, out of his John-Lennon frequented London restaurant, SEED.^{30, 31} In 1979, a popular restaurant in Boca Raton, Florida unveiled a meatless soy protein patty that by 1993 was the flagship product of Boca Burger Inc.³² In 1981 Oregon, Paul Wenner, operating the bustling vegetarian Gardenhouse restaurant, grilled some leftover rice, cheese, and veggies into patty form. In 1992, Gardenburger, Inc. went public, and meatballs, wings, and cutlets later became part of the booming business.³³

“The secret of the VegeBurger was simple in retrospect,” Sams writes on his website. “It had a better flavour than your average beefburger, cost you less, didn’t kill cows, and made you feel a whole lot better.”

A slew of other companies entered the market with their own, usually frozen takes, on the trend. These companies didn’t accurately replicate meat, but they did provide an easy source of protein for those who were already vegetarian, for health or religious reasons. “I would never eat a GardenBurger and think that I was eating a real burger, right?” Sayer says. “But an Impossible Burger can trick me.”

Miri Eliyahu, an economic sociologist and PhD candidate at Northwestern University, says that this new generation of plant-based proteins aim to appeal to meat lovers by closely replicating meat’s properties.³⁴

“Plant-based products have been around for a long time. While they’ve been successful in attracting the population that’s already looking for an alternative, Impossible Foods wants to do something much bigger than that,” says Esther Cohn, communications manager at Impossible Foods. “Our mission is to displace and ultimately overthrow demand for the incumbent industry, which is animal agriculture.”³⁵



On a summer day a few years ago, Jayne Myers’ local grocery store in Summit, New Jersey, was having a cook-out in the parking lot. She was walking around, hungrily scoping out samples, when an employee handed her a small piece of a hamburger.

She ate it quickly. She noticed that it tasted a little “different,” but enjoyed it until the employee told her what it was. She had just had her first taste of Beyond Meat.

“When they told me, psychologically, it then all of a sudden grossed me out,” Myers says. “I was like, ‘Okay, how many chemicals did they use to make this taste like hamburger meat?’”

Myers has always liked both veggie and meat burgers. The new generation of plant-based meats...not so much. Her 23-year-old daughter has recently gone vegan, but when Myers has tried to cook the novel faux meat for her at home, she says she becomes overwhelmed by a “pungent, chemical smell” that she struggles to describe. Myers says she would be willing to try a patty that tasted like meat but was made only of vegetables, without a long ingredient list.³⁶

Cohn says Impossible doesn't hide behind the fact that their product is processed. "We think it's a really smart and intentional process that was created by scientists."

"Our products shouldn't be compared with kale salad and roasted broccoli," Cohn says. "It's certainly gone through much more processing than those products have, but that's not what we're trying to replace. What we're trying to replace is this behemoth, animal-based agriculture system."

Like most things in life, the novel vegan products aren't necessarily healthy or unhealthy. When compared to a beef burger, the meatless burgers tend to lack cholesterol, but have much higher levels of sodium, and similar levels of saturated fat, calories, and protein.³⁷ Many of the main ingredients are likely recognizable to most consumers. The first three ingredients in Beyond Meat are water, pea protein, and expeller-pressed canola oil.³⁸ Impossible's are water, soy protein concentrate, and coconut oil.³⁹

And Myers doesn't shy away from all "processed" foods. Her favorite new snack is the new pink and green, limited-edition Lady Gaga Oreos. But there's something about the taste, smell, and idea of the novel meatless meats that feels off to her.

Critiques of the products almost always seem to come back to at least a vague mention of "taste." About seven in ten Americans say they would consume more plant-based food products in place of meat, if they just tasted better.⁴⁰

"I guess I'm a psychological eater," Myers says. The truth is, so is everyone else.

Taste is a complex physical, sensory, and cognitive process which involves far more than just the mouth. University of Pennsylvania psychologist Paul Rozin, who has spent his career studying taste perception and disgust, has a go-to example of how food aversion is driven, in part, by powerful psychological processes: Briefly submerge a sterilized, dead cockroach into a glass of fruit juice, and few people will take a sip. No one cares how freshly-squeezed, perfectly tart, or icy cold the juice is, or that the cockroach has been thoroughly sanitized. The mere thought of ingesting an apparently tainted drink is viscerally repulsive to most.

"Disgust is the strongest reaction people have to food," Rozin said in an interview with the University of Pennsylvania.⁴¹ Some stimuli, especially those associated with pathogens, are almost universally "gross." It's not just the faint of heart who recoil at the smell of rotting food or the sight of vomit.

Many are also repulsed by tastes and textures that others enjoy. Think pineapple on pizza — or the fact that Sayer likes both Beyond and Impossible, Myers dislikes both, and many consumers prefer one over the other. Why is that?

Much of it has to do with individual and cultural expectations. Cheese, a cornerstone of diets in the United States and Europe, is viewed as disgusting by many in parts of Asia. Raw fish in sushi was unpopular in America until a few decades ago. An American studying abroad in Ireland may initially hesitate to sample blood pudding but grow to enjoy the food with time — and maybe a little encouragement. The simplest way that people overcome food aversion, Rozin said in the University of Pennsylvania interview, “is exposure in a positive context, with other people around you enjoying it. People begin eating ‘disgusting’ things like sushi and raw meat basically by being coaxed by others they like and respect.”⁴²

In one recent (and amusing) experiment demonstrating the importance of context on taste, 100 participants wearing virtual reality headsets were given chocolate. Before they ate, half of them saw a VR dog make a chocolate-like poop on the table in front of them. Participants who had seen the dog do its business were less likely to consume the actual chocolate than participants who just looked at a blank table with a piece of chocolate on it through the headset.⁴³

According to Sayer, increasingly concerned with global warming and animal mistreatment, she found the physical sensation, the “mouthfeel” of meat, unappealing. Myers’ opinion of the burger at the grocery store changed from delicious to gross after perceiving it as a chemical-laden impersonator.

Others have similar impressions, Fanzo says. “They call it ‘fake food’ in a lot of Europe. So they just think, ‘if I want a piece of steak, I’ll just eat it every once in a while,’” Fanzo says. “I think [the novel vegan substitutes] are going to struggle on that front.”

Despite the wide range of preferences and values which drive people’s tastes, nearly everyone has one type of food that they enjoy most. A great deal of psychological research, some of it conducted by Rozin, confirms that familiarity plays a large role in children’s acceptance of new foods. Even being visually exposed to new foods, such as in a store, at school, or on TV, can make a child more willing to try them.⁴⁴

“Why do we think that beef is the gold standard for what a burger needs to be?” says Heather Smyth, a flavor chemist and sensory scientist at the University of Queensland in Australia. “It’s just what we’re used to. And there’s a lot of power behind familiarity.”⁴⁵

Scientists behind the novel vegan meats have worked hard to capitalize on the power of familiarity, striving to make products that look, cook, smell, and taste like the meat so many know and love. To achieve that, they've asked the questions: what are the defining characteristics of meat, and how can we replicate them without animals?

Ethan Brown, the CEO of Beyond Meat, said in a 2019 interview with Foodbeast that his company focuses on five key components of meat: amino acids, lipids, minerals, vitamins, and water. "What we're doing is assembling each of those pieces in the architecture of animal protein," he said. "You can say, 'yes, meat comes from a chicken, cow or pig,' or you can say, 'meat has these five things and they present in this fashion.'"⁴⁶

To design plant-based meat, scientists can use ingredients which behave like various aspects of animal meat. Coconut oil, for instance, is thicker and richer than most plant-based oils, like olive and canola. Like animal-based fats (and unlike most plant-based fats), coconut oil is solid at room temperature. For this reason, it works as a key ingredient in both Beyond and Impossible products. It can even be inserted in small chunks to emulate the way fat is distributed in a beef patty.⁴⁷

For protein, Beyond uses a combination of pea, rice, and mung bean proteins.⁴⁸ Impossible uses protein from soy and potato.⁴⁹ To force crunchy plant materials to have meatier texture, scientists may process them in ways that can remove some natural nutrients. The companies then fortify their products with vitamins and minerals often present in meat, leading to long, sometimes unfamiliar-looking ingredient lists.^{50, 51}

And then there's appearance. Impossible Foods has given its products a meaty appearance in part thanks to heme — which the company refers to as its "magic ingredient." Heme is an iron-rich molecule found in both animal and plant tissues, though it is very plentiful in animal muscle tissue. It provides meat with much of its distinctive, bloody, aromatic flavor and color.

Impossible figured out how to make large quantities of plant-based heme, listed as "soy leghemoglobin" on the product label.⁵² It's produced by first extracting DNA from soy plants and then putting it into genetically-engineered yeast, which are fermented in a process similar to beer production.⁵³ The result is a plant-based heme, that, in 2019, the United States Food and Drug Administration approved as safe for use.⁵⁴

Beyond took a different approach to producing a meaty color, opting for beet juice extract to dye their products the color of rare beef. It allows them to call their products GMO-free.⁵⁵

Beyond and Impossible aren't alone in their quest. Dr. Praeger's, a plant-based food company founded more than 25 years ago, launched their "Perfect Burger" in 2019, a new formula

designed to look, cook, and taste like beef.^{56, 57} The same year, Morningstar Farms, a long-time producer of vegetarian soy patties and links, released an entire line of what they call “next-generation” hyper-realistic faux meats called, charmingly, Incogmeato.^{58, 59} Even meat giants like Tyson Foods have begun selling plant-based meats under new brands — theirs is called “Raised & Rooted.”⁶⁰

But producing a synthetic version of a wildly popular, ubiquitous food places it squarely in competition with the original. For consumers like Myers, the novel vegan meat substitutes will always be compared to animal products. After all, they taste, look, and smell almost — but not quite — exactly like meat.

In that way, the products may still exist in a sort of “uncanny valley.” The uncanny valley is a term devised by scientist Masahiro Mori in 1970 when he was studying robot design.⁶¹ Mori noticed that people are unlikely to have strong affinity for a robot with absolutely no human-like characteristics, something like, for instance, today’s cylindrical Amazon Alexa. But add a human-like feature, maybe two little dots for eyes and a little curved-up semicircle of a mouth, and people start to find it cute.

At a certain point, however, the pattern breaks. The more realistic a robot becomes, maybe with human-like hair and skin, the more people begin to describe it as unnerving, creepy, and weird. That is, unless it were able to become completely and truly indistinguishable from what it’s imitating.

The uncanny valley, if plotted on a graph, would be something like a U-shape: with similarity to the original on the X-axis and consumer affinity on the Y-axis. When something is in the uncanny valley, it’s in between being clearly distinct from and completely identical to the original, and its acceptance is low. Some have even conjectured that the 2019 *Cats* remake, starring computer-generated human cats, was so revolting to audiences because its characters were in the uncanny valley.⁶²

Items in the uncanny valley are unfamiliar, uncomfortable, and often seem to defy categorization, one of the human brain’s most central cognitive tasks. Categories act like a mental filing cabinet, helping people and animals navigate their complicated surroundings and avoid danger.⁶³ Categories help explain why an innocent house spider can prompt a quickening pulse— the brain automatically files it into the scary category of “dangerous bugs.”

Impossible states on their website: “Before Impossible Foods, there was meat and there were plants.”⁶⁴ Steak, chicken, and bacon are all examples of items that clearly fall into a “meat” category — familiar items that we know to be safe to eat. Broccoli, carrots, and peas obviously

belong to the “vegetable” category — also familiar items that we know to be safe to eat. But what about “novel plant-based vegan meat”? What category does that belong to?

For the scientists aiming to break down the experience of taste, perhaps the most useful tool is a group of people ready to eat just about any weird thing that’s put in front of them. And that’s exactly what Smyth, the Queensland flavor chemist, has.

Major multinational food companies often approach Smyth to work with her highly-trained 12-person sensory panel. The lab coaches its panelists on how to assess and describe food in a way that is useful to scientists working on new ingredients or recipes.

Smyth has devised a taste testing method called “temporal descriptive profiling,” which helps tasters describe how flavor and texture of food evolves as it is chewed and swallowed. “One of the things that I need to consider in those sensory methods is not only how the food tastes and smells and feels on that first bite, but through the whole consumption period,” she says.

When a panelist arrives at the lab, they enter a small, isolated booth containing a tray of samples. The samples are usually variations of the same product, often with different concentrations of a particular ingredient. Some of the samples may be grocery store or restaurant items, but others have been designed in Smyth’s lab.

As they eat, the panelists rate various attributes of each sample on an iPad. They make notes about things like how oily, crunchy, or salty it is, how those sensations change as it is eaten, how long the flavor sticks around in their mouth, and so on. Individual differences like chewing rate, saliva production, and mouth movements can affect how different people react to various recipes. Smyth’s lab takes all of that into account. Tasters test all kinds of foods: colas, potato chips, coffee, seafood, and, recently, a lot of plant-based proteins.

What makes Smyth’s lab unique, she says, is the variety of mechanical tools used to study food in addition to human tasters. One is a ring shear tester. Smyth’s team crushes up food, like a small piece of hamburger, into a powder, and inserts it into the round, silver device. They are then able to closely study things like how the food particles stick together as more moisture is added, how the particles rub up against one another, and how those traits might affect sensory experiences like how easy the food is to chew and swallow. There’s also a penetrometer, a device that is used to gauge springiness and texture. It has a small rod which presses into a sample of food and measures resistance, revealing if a recipe is too tough or too mushy. Those

are just a few of their tools. They even have one which evaluates how real human saliva interacts with food particles.

“We play around with different ingredients, different formulations to test to see which direction to go,” Smyth says. “If we reduce the salt, what happens? What if we increase the fat content or use a different fat? What happens if we treat the protein beforehand differently?” Then, they bring in the sensory panel to try the results. The loop can run multiple times.⁶⁵

Currently, Smyth’s group is collaborating with Motif FoodWorks, a plant-based food technology company, located in Boston. Motif launched in 2019 with \$90 million in funding from a biotechnology company called Gingko Bioworks, which has worked with everything from fermented perfume ingredients to cultured cannabinoids. They also raised an additional \$119 million in Series A funding.^{66, 67}

Motif scientists want to shorten ingredient lists for plant-based substitutes, increase their health benefits, and most importantly, decode that vague thing we call “taste” — all in hopes of improving dairy and meat analogues so that people really want to eat them.

Mike Leonard, Motif’s chief technology officer, worked for sixteen years in the food industry, at large food companies including Kraft Heinz and PepsiCo before joining Motif. “Spending so much time in the industry, I realized that there are a few trends that will really drive the future of food,” Leonard says. Plant-based replacements, he believes, are chief among them.

“Consumers are very willing to purchase plant-based foods and try them, but to try them again is kind of a barrier for a lot of people,” Leonard says. “Because the foods just don’t taste that good.”

Leonard points to results from a June 2020 consumer panel. It measured the percentage of consumers who have bought a certain product at least five or more times, a sort of proxy for how satisfied consumers are with that product. While more than half of people purchase a given fresh meat product five or more times, less than 30% will purchase the same meat plant-based meat product more than five times.

For Leonard, it’s clear what the most pressing challenges are to getting these products accepted: “Number one is taste. Number two is taste. And number three is taste,” he says.

“We’re coming at this challenge of how to make plant-based foods craveable from a very holistic perspective,” Leonard says. “We’re not just designing one or two ingredients to address a few discrete gaps in experience. We’re looking to redesign the whole experience.”^{68, 69}

Some of Motif's work is done through an internal science team, but the company also partners with research groups like Smyth's.

Smyth's lab uses its mechanical and sensory tests to measure, for example, how tasters react to a certain ingredient and whether that ingredient affects friction or viscosity while chewing. Then, they share their knowledge with Motif and its other partners, like scientists at the University of Guelph in Ontario, who study new ways of making animal-free fats, or the team at the University of Massachusetts Amherst, who aim to improve the solubility, stability, and color of proteins.

For now, making a realistic plant-based burger requires a lot of highly-processed ingredients, Smyth says, "but the more we learn, the more we're able to swap out those types of ingredients for natural processes or natural alternatives that will give it a better, healthier, more equivalent burger sensation."

Motif is currently working on multiple ingredients and products which they hope will improve the texture and flavor of plant-based foods. The plan is to sell them to consumer-facing companies for use in new or existing recipes. The first two products are designed to improve the taste and the texture of meat alternatives, and will be commercially available in late 2021 and early 2022, respectively.

Leonard envisions a future supermarket in which a shopper pushes their cart down the packed meat aisle, pausing to consider an animal-based product and a plant-based one. Leonard hopes that whichever product they choose, they'll get the same great experience, without a single trade-off. And while taste is the first hurdle to realizing that vision, he acknowledges, it's not the only one.

College senior Alex Koehl used to eat meat multiple times a day. By the start of his senior year, he was no longer able to stomach the industry's environmental effects. He gave up all animal products except for eggs.

Koehl's mom is Italian, and he recently attempted her beef pasta sauce recipe with meatless meat. "I was sad to not be able to cook that recipe anymore, so I tried it with the Impossible crumbles," he says. "It was totally the same to me."⁷⁰

More than three-fourths of Americans report that easy, quick preparation is at least moderately important when deciding if they want to purchase and consume plant-based foods. That's one area where these novel plant-based proteins excel.⁷¹ "With [vegan] sausages and burgers, all you

have to do is cut it like normal meat,” Koehl says. “With tofu, it’s kind of a pain to do the pressing, cutting it up yourself and all that stuff.”

Though he enjoys them, Koehl buys the products infrequently.

Plant-based meat products’ high price points makes them unattractive — if not completely inaccessible — to many Americans. Whole Foods’ Amazon delivery service in St. Louis, Missouri, where Koehl attends college, shows a pound of Beyond Beef plant-based grounds sells for \$9.99 while a pound of 80% lean ground beef sells for \$4.99.

One in five Americans in households with incomes under \$50,000 lack access to a nearby grocery store, and may be more reliant on what’s available in convenience, gas, and fast-food shops. More than half of Americans in that income bracket agree that it is “too much of an effort to buy plant-based foods.”⁷²

Plus, these novel products are generally found in the meat aisle alongside real beef, pork, and chicken, unlike old generations of veggie substitutes that have often been relegated to a desolate shelf in the frozen section. The placement boosts visibility, but it also ensures that the price difference is glaringly obvious.

It goes back to Leonard’s concerns about repeat purchases. If a customer shells out the money to try the pricier vegan product and then finds that it is just not worth the price, why would they purchase it again?

While Koehl enjoys the novel vegan products on occasion when he’s craving meat, he mostly just relies on tofu, lentils, and beans.

It’s common for new products and technologies to have steep price tags in their early stages. Lower prices may come with time — if the products gain popularity. Increased demand would lead to increased supply, and ultimately lower the cost of the final product to consumers, Fanzo says. In turn, more people might want to try the cheaper products.

Impossible has cut their prices three times in the past year (twice for food service and once for retail, according to Cohn) and plans to keep doing so. Ultimately, the company hopes to price their products lower than meat products.

Patrick Brown, Impossible’s CEO, says his company is working to increase access: production has ramped up six-fold between 2019 and early 2021, and he anticipates cutting prices further as they continue to grow.⁷³ At the beginning of 2020, Impossible products were found in only about

150 grocery stores nationally. Over the next six months, they expanded sales to more than 11,000 grocery stores in all 50 states.⁷⁴ Beyond Meat now sells at about 28,000 retailers nationally.⁷⁵

Last year, both companies launched direct-to-consumer websites, where customers can order the products in bulk.^{76,77} Customers can increasingly find the products at major chains like Burger King, Pizza Hut, Starbucks, and Subway.

2020 was also the year that many American consumers witnessed a world where meat was limited or unavailable. Meat-packing facilities were the site of many of the United States' early, large COVID-19 outbreaks, due to a multitude of factors including cramped workspaces.⁷⁸ For the week ending April 25, cattle slaughter rates in the United States were down 28% in 2020 as compared to in 2019.⁷⁹ Large national grocery store chains like Costco, Hy-Vee, and Kroger, as well as many local stores and regional chains, began to limit consumers' meat purchases.⁸⁰

Meat supply in the US bounced back.⁸¹ Still, the crisis highlighted existing issues in the industry, Donnan says — in animal hygiene, worker safety, and greenhouse gas emissions. “They know they have to change their business models,” he says. “What COVID is doing is accelerating that change.”

On April 3, 1973, Motorola engineer Martin Cooper, on the streets of Manhattan, made the world's first phone call on a cellular phone — ringing his defeated rival at Bell Labs.

The very next morning, the Associated Press sarcastically suggested a cell phone user could take their almost three-pound device “to the beach, the supermarket, the yacht, the fox hunt, the golf course, the hideaway where you went to get away from it all.” Critics contended that constant connectedness would overwhelm and repel users. Many argued that the device was too clunky, impractical, and pricey to ever gain acceptance.⁸² Cooper believed that people were inherently mobile and social, and that phones should reflect those traits.

The technology in Cooper's cell phone wasn't commercialized for another ten years, and even then, it cost the equivalent of nearly \$10,000 today. It's known as a “brick phone” because it looked like and weighed as much as a brick.

Cell phones weren't catapulted to dominance the moment Cooper triumphantly called his opponent. Rather, they gained popularity with the incremental technological improvements, increased accessibility, slowly dropping prices, and wider consumer acceptance that followed over the next several decades.

New technological advances don't follow a preordained arc, says Benjamin Wurgaft, a writer and historian who studies food culture and the future of food. We may not be able to predict the future of meat and its replacements, he says. Yet, with time, people may come to accept, even embrace, new technologies — especially when they fulfill a serious need. “Why haven't people solved the problem of meat yet? Because it hasn't been a problem,” Wurgaft says. “But it became one over the last 40 years.”⁸³

The American public is growing increasingly aware of the climate crisis. In 2013, 40% of Americans believed climate change was a major threat to the United States. Five years later, that number was close to 60%.⁸⁴ While preventing climate disaster is not the responsibility of any individual, many consumers want to be part of the change. Eliyahu and Donnan say that younger generations, including millennials, are more likely to be “values-based” shoppers — eager to buy products that align with their underlying beliefs and morals.

“When you have a values-based movement, like the plant-based movement, where people are making food choices because of what those choices represent for their health, for the planet, and for society,” Leonard says, “that's the kind of underpinning that really drives sustainable growth and exciting opportunities.”

Seemingly small changes may lead the way. Jayne Myers' vegan daughter has convinced the family to try meatless Mondays. It's the making of a new tradition.

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