

A Fresh Take on Fake Meat

Melissae Fellet

Can scientists deliver a meatless burger that tastes good and will not harm the planet?

For some, the pleasure of eating meat comes served with a side of guilt. Raising animals for food contributes to climate change, water pollution, and habitat destruction. Governmental dietary recommendations and social campaigns like Meatless Monday pepper us with messages to eat less meat, particularly red meat. But for meat lovers, come dinnertime, alternative protein sources, like beans or soy-based meat substitutes, are no match for the experience of eating a burger. Taking a bite, the meat feels dense, it rebounds as you chew, and juices squirt into your mouth. Consumers crave it, and global demand for meat is projected to skyrocket.

Now scientists are using food science, biotechnology, and tissue engineering to develop new meat substitutes with the taste, texture, and appearance of meat—to deliver the pleasure, without the environmental consequences. Chicken strips, ground beef crumbles, and burgers made with these techniques are already appearing on grocery store shelves, made by companies with reported funding from tech giants like Microsoft's Bill Gates, Google cofounder Sergey Brin, and Twitter founders Biz Stone and Evan Williams. Whether driven by a desire to save the planet or make healthier foods, these food innovators hope high-tech toolkits will help create products that meat eaters love.

Pat Brown's Impossible Dream

"Our target consumers, which are the only ones that are going to make a difference for the mission, are hard core,



This 100% plant-based burger from Impossible Foods gets its color from a protein called leghemoglobin. Image Credit: Impossible Foods.

uncompromising meat lovers", said Patrick O. Brown, to a crowd at the fall 2015 American Chemical Society meeting in Boston. Brown, a renowned biochemist who pioneered DNA microarrays in the 1990s, left his professorship at Stanford University to start [Impossible Foods](#), a Silicon Valley food start-up, bent on upending what he calls "the world's most destructive industry". If the company can make plant-based products that meat and dairy lovers prefer over what they consume today, he believes consumer demand for his products will unseat animal agriculture as the source of beloved burgers.

There's something about the combination of muscle, connective tissue, and fat that makes up meat that is unmistakable. As Brown notes, the taste of meat cannot be confused with anything else. And, he says, people do not love meat because it comes from animals or uses too many resources, but because of its deliciousness. To achieve a fake meat that will convert meat lovers requires homing in on the flavor, aroma, texture, and appearance that gives meat its essence. There's opportunity to boost nutrition, too: providing more protein than beef without cholesterol, hormones, or antibiotics. This combination is what Impossible Foods is chasing.

Meat flavors and aromas come from thousands of volatile small molecules released by muscle and fat cell destruction. Flavor precursors start with an animal's diet, which

Meat's costs by the numbers

Percentage of global greenhouse gas emissions from raising livestock:	Fraction of world's ice-free land used to produce livestock, including growing feed:	Projected percentage increase in global meat demand by 2050:	Liters of water needed to produce 1 kg of beef:
14.5	1/3	73	15,400

Sources: Food and Agriculture Organization of the United Nations; *Ecosystems* 2012, DOI: 10.1007/s10021-011-9517-8.

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influences the molecular composition of its cells. After slaughter, enzymes in an animal's muscle cells begin breaking down biomolecules into simpler amino acids, sugars, and fatty acids. This means some flavor molecules develop even as the meat ages during its trip to the store. Other flavor and aroma components emerge from reactions between sugars, amino acids, or fatty acids as the meat is cooked.

Central to this is myoglobin, a protein in muscle cells that carries oxygen. Myoglobin contains heme, a porphyrin ring with an iron atom bound in the center. When myoglobin denatures as meat cooks, it releases the heme. Some iron in turn escapes the heme and catalyzes flavor- and aroma-forming reactions. The iron in myoglobin is also responsible for the color change of meat as it cooks, oxidizing from a red Fe(II)–heme complex to a brown one that contains Fe(III).

A key, then, to making a convincing plant-based burger, according to Brown, is recreating these reactions. Impossible Foods has focused on leghemoglobin, a protein similar to myoglobin that is found in nodules on the roots of legumes. Company scientists are producing this protein in yeast and adding it to their burger to do the chemistry needed to make meaty flavors and aromas.

To recreate the textures of muscle, fat, and connective tissue, the scientists at Impossible Foods mine a proprietary toolkit of proteins and fats, purified from crude plant extracts and chosen for their physical, chemical, and textural properties. The company offers no details about what these are, but they say their burger has the juiciness and texture of regular meat, even developing a crust when cooked. With their methods, the company adds that its scientists could also make bacon, fish, chicken, milk, or cheese.

Tackling Texture

Many of the meat substitutes available today are made from a mix of soy and wheat gluten called texturized vegetable protein. They tend to take the form of thin, spongy patties, some colored brown to look like beef, and others breaded to resemble a chicken nugget. Food scientists add soy sauce, mushroom extract, or yeast extract to boost umami, the taste attributed to foods containing the amino acid glutamate that is often described as a characteristically meaty flavor. But visual similarities and added savory flavors are not enough to sway mouths accustomed to meat.

“Taste can be achieved”, says [Raffael Osen](#) of the Fraunhofer Institute for Process Engineering and Packaging IVV, in Germany. “But texture, juiciness, and bite—this is difficult.” To get a more fibrous, meatlike texture from plant-based protein, Osen worked with other European Union researchers to develop a way to stretch globular plant proteins into strings and to encourage them to cling together



High-moisture extrusion of soy powder, wheat gluten, and starch creates strips with a fibrous texture similar to meat, as in these imitation chicken strips. Image Credit: Keshun Liu.

into fibers. The project, called [LikeMeat](#), targeted meat alternatives that were satisfactory enough to replace meat used in chicken nuggets, for example, but might not be meaty enough to replicate a fine steak.

The method uses a technique known as high-moisture extrusion. Operators pour water and powdered proteins, often soy or yellow pea isolates, into a machine with two long, intertwined screwlike shafts extending through controlled temperature zones. The temperature control allows the mixture to be heated as the screws mix and knead the ingredients traveling down the chamber. The plant proteins unfold, thanks to the heat, and align in the direction of the flow as they move through the screw. Then, at the end of the extruder, a cooling die causes the mixture to solidify and develop a fibrous texture. A final step in the process shapes the mixture into strips, crumbles, or other forms.

Details about how the processing parameters and protein source impact the final product texture are under wraps. But Osen and his colleagues have experimented with boutique proteins derived from locally grown crops like peas, lentils, and lupin to produce vegetarian burgers, schnitzel, and meaty pasta sauce. [Keshun Liu](#), a research chemist at the U.S. Department of Agriculture's Agricultural Research Service, and [Fu-Hung Hsieh](#), a professor of bioengineering and food science at the University of Missouri, have also worked to develop this method, and their research shows that disulfide bonds formed between denatured soy proteins account for the fibrous texture.

Both Osen and Hsieh are involved with companies producing alternative meat products using high-moisture extrusion. In Germany, Osen says, there's an interest in eating less meat, yet there are fewer options on grocery store shelves than in the U.S.

The California-based food producer [Beyond Meat](#) licensed Hsieh's high-moisture extrusion process, and built a plant in Columbia, Mo., near the university. The company's chicken and ground beef are already available in some stores. Food writer and cookbook author Mark Bittman, in a column for the *New York Times*, said he could not tell the difference between a wrap containing real chicken and one with the Beyond Meat chicken strips. Chef Alton Brown, tasting the product for *Wired* magazine, estimates the strips could replace chicken in "at least 30% of the existing chicken recipes floating around out there, and that's a few hundred thousand (depending on who you ask)."

Cellular Agriculture

One way to get around the challenges of using plant proteins and fats to recreate the taste and texture of meat is to use real meat cells instead. Much like tissue engineering grows new organs in the lab, this approach grows muscle cells in culture. A team led by [Mark J. Post](#) of Maastricht University, in the Netherlands, was the first to unveil a lab-grown hamburger produced from thin strips of cultured beef.

To create the strips, the researchers first isolate muscle cells from a piece of cow tissue. As the cells grow in culture, they form tubes 0.3 mm long, which the researchers then wrap around a cylinder of gel. The tubes grow into each other and naturally contract. Because of their circular arrangement, this contraction generates tension in the tubes, which encourages protein production and natural muscle tissue development into small fiber bundles. After 3 weeks, the researchers harvest a ring of tissue and slice it open to get a 25-mm-long strip.

The process is not yet anywhere near as efficient as growing cow cells in a cow. The lab's 85-g burger, unveiled in August 2013, used about 10,000 strips of muscle, and at the time, reportedly cost more than \$300,000 to produce, grown on nutrient-rich medium containing glucose. And while tasters said the burger had an "intense taste close to meat" and a "familiar mouthfeel", some noted that the muscle-only patty was a little lean. Post said the team is working on culturing fat cells to combine with the lab-grown muscle tissue. They also hope to tailor the culture conditions to get the composition of muscle proteins actin, myosin, and myoglobin that produces a natural taste—and with an efficiency to allow large-scale production.

Though culturing tissue requires energy to sterilize equipment and stir fermentation tanks, a [2011 life-cycle analysis](#) suggests that, with even a little scale-up, the process could be better than a cow. Growing 1,000 kg of meat with nutrients from cyanobacteria would use much less energy, water, and land, and the process would generate dramatically less greenhouse gas than traditional beef production, according

to the analysis. Applying standard biotechnology and engineering techniques to the process should bring the costs down, says Isha Datar, executive director of [New Harvest](#), a New York based nonprofit that awards grants to researchers working on "cellular agriculture".

Meat is not the only target for this technology. Datar says the group is trying to kick-start an industry for animal products made without animals. New Harvest recently collaborated with a start-up company called [Clara Foods](#) that is producing egg white proteins in yeast; the proteins can be fried just like a regular egg, added to cake batter, or whipped into a meringue. Within six months of starting at a San Francisco biotech accelerator, a cell biologist and his business partner developed the product and raised \$1.75 million in seed funding.

It remains to be seen whether these new products will sate our carnivorous desires. Investors seem willing to take a gamble, though, and Impossible Foods's Brown is optimistic, noting that technology has eliminated animals from our daily lives before. About two hundred years ago, horses were the fastest transportation, one even winning a race against the first mechanized transportation, the steam locomotive. While horses have not gotten much faster since then, Brown says, the performance of mechanized transportation improves every year. He thinks Impossible Foods is in a similar position with respect to food. "We're getting better every day, and we're going to continue to get better", he says, "... in ways the cows can't."

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