ANNALS OF SCIENCE

# TEST-TUBE BURGERS

*How long will it be before you can eat meat that was made in a lab?*

BY MICHAEL SPECTER

*Scientists start with just a few grams of meat. Photograph by Hans Gissinger.*

Willem van Eelen was born in 1923, the son of a doctor, and a child of colonial privilege. His father had recently been dispatched to the Dutch East Indies, and van Eelen wanted for nothing. "I was a spoiled boy and gave little thought to the world around me," he said not long ago, as we sat in the study of his modest apartment, which overlooks the broad waters of the Amstel River, in Amsterdam. His youth of oblivious freedom ended abruptly on May 10, 1940—the day the Nazis invaded the Netherlands. Van Eelen was just sixteen, but, like many of his contemporaries, he lied about his age, enlisted, and served in Indonesia.

The Dutch fought frantically to prevent Japan from seizing their most valuable colony, but they failed. Van Eelen was captured, and spent most of the war as a prisoner, dragged forcibly from one P.O.W. camp to the next. Now, at eighty-seven, dressed in khakis, penny loafers, and a casual gray shirt, he projects the contemplative air of a philosopher. Van Eelen is a genial man who laughs easily. But when asked about the camps, he lowered his voice and slowly closed his eyes.

"These were cruel places," he said. "We worked from morning to night building airstrips. They beat us like dogs. For food, there was almost nothing. The Japanese were harsh with us, but they treated animals even more brutally, kicking them, shooting them. By the time the Americans liberated the camp, I was so close to death that you could see my spine from the front. The soldiers would ask my name, but I didn't have enough strength to say the words."

After the war, van Eelen studied psychology at the University of Amsterdam, but he struggled with the intertwined memories of starvation and animal abuse. He began to attend scientific lectures, and, during one of them, about how to preserve meat, van Eelen was seized by an idea: "I wondered, Why can't we grow meat outside of the body? Make it in a laboratory, as we make so many other things." He went on, "I like meat—I never became a vegetarian. But it is hard to justify the way animals are treated on this planet. Growing meat without inflicting pain seemed a natural solution."

"Meat" is a vague term and can be used to refer to many parts of an animal, including internal organs and skin. For the most part, the meat we eat consists of muscle tissue taken from farm animals, whether it's a sirloin steak, which is cut from the rear of a cow, or a pork chop, taken from flesh near the spine of a pig. In-vitro meat, however, can be made by placing a few cells in a nutrient mixture that helps them proliferate. As the cells begin to grow together, forming muscle tissue, they are attached to a biodegradable scaffold, just as vines wrap around a trellis. There the tissue can be stretched and molded into food, which could, in theory, at least, be sold, cooked, and consumed like any processed meat—hamburger, for example, or sausage.

"This became my fixation," van Eelen continued. "Everything I have done since that day I have done with this goal in mind." After university, van Eelen went to medical school, where he spoke to biologists, research scientists, and anyone else he thought could help. Most people laughed when they heard about his project—in part, perhaps, because van Eelen is more of a scientific enthusiast than a sophisticate. When he told his professors that he wanted to grow meat in a lab,

most acted as if it were a prank. But one teacher took him aside. "He said if I was serious I would need to raise money for research," van Eelen recalled. He promptly quit his medical studies and went to work. With his wife (an artist, who died many years ago), he ran a series of art galleries and restaurants. The couple funnelled whatever money they managed to save into his odd obsession.

Van Eelen has been chasing his goal ever since, but it took decades for the science to catch up with his imagination. That began to happen in 1981, when stem cells, which can divide almost endlessly and have the ability to develop into many types of tissue, were discovered in mice. Van Eelen recognized the potential immediately, although there was little initial interest in turning muscle cells into meat. By then, he was used to rejection, and he persisted. Finally, in 1999, more than half a century after he attended the lecture that fuelled his quest, he received U.S. and international patents for the Industrial Production of Meat Using Cell Culture Methods. For the first time, serious people began to take him seriously. Pointing to the channel waters outside his window, van Eelen said, "For all those years, there was not one gram of meat made. At times, I wanted to jump right into that river."

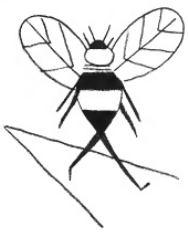
He no longer feels that way, and for good reason: a new discipline, propelled by an unlikely combination of stem-cell biologists, tissue engineers, animal-rights activists, and environmentalists, has emerged in both Europe and the United States. The movement started fitfully but intensified when, in 2001, NASA funded an experiment, led by Morris Benjaminson, that focussed on producing fresh meat for space flights. Benjaminson, a biological engineer at Touro College, in New York, cut strips of flesh from live goldfish and submerged them in a nutrient bath extracted from the blood of unborn cows. Within a week, the fish pieces had grown by nearly fifteen per cent. While the results were not meat, they demonstrated that growing food outside the body was possible. Then, in 2004, after continued lobbying from van Eelen, the Dutch government awarded two million euros to a consortium of universities and research facilities in Amsterdam, Utrecht, and Eindhoven. Though the grant was small, it has helped turn the Netherlands into the in-vitro-meat world's version of Silicon Valley.

Van Eelen was not the only man undaunted by indifference to the idea of lab-grown meat. Vladimir Mironov, an associate professor in the Department of Cell Biology and Anatomy at the Medical University of South Carolina, is working on several experiments, most of which focus on finding an efficient way to grow it. Mironov, a well-known tissue researcher, was brought up in Russia and studied at the Max Planck Institute with the pioneering vascular biologist Werner Risau. Then, in the early nineteen-eighties, he moved to the United States, where he became intrigued by the possibilities of making meat. "A few years ago, I tried to get a grant," Mironov told me when I visited his lab, in Charleston. "I failed. I tried to get venture capital. Failed again. I tried to approach big companies for funding. Failed again. But slowly, very slowly, people are coming around."

Teams are forming at universities around the world. Some are interested primarily in animal welfare, others in regenerative medicine; still others see lab meat as a potential solution to an environmental crisis. They all share a goal, however: to grow muscle without the use of animals, and to produce enough of it to be sold in grocery stores. "This is a no-brainer," Ingrid Newkirk, the co-founder and president of People for the Ethical Treatment of Animals, told me. Three years ago, the animal-rights organization, which has a singular gift for public relations, offered a million dollars to the first group that could create "an in-vitro chicken-meat product that has a taste and texture indistinguishable from real chicken flesh." More recently, PETA provided funding for Nicholas Genovese, a postdoctoral biological engineer, to work in Mironov's lab—a sort of PETA fellowship. Newkirk explained, "If people are unwilling to stop eating animals by the billions, then what a joy to be able to give them animal flesh that comes without the horror of the slaughterhouse, the transport truck, and the mutilations, pain, and suffering of factory farming."

Meat supplies a variety of nutrients—among them iron, zinc, and Vitamin $B_{12}$—that are not readily found in plants. We can survive without it; millions of vegetarians choose to do so, and

billions of others have that choice imposed upon them by poverty. But for at least two million years animals have provided our most consistent source of protein. For most of that time, the economic, social, and health benefits of raising and eating livestock were hard to dispute. The evolutionary biologist Richard Wrangham argues, in his book "Catching Fire: How Cooking Made Us Human," that the development of a brain that could conceive of cooking meat—a singularly efficient way to consume protein—has defined our species more clearly than any other characteristic. Animals have always been essential to human development. Sir Albert Howard, who is often viewed as the founder of the modern organic-farming movement, put it succinctly in his 1940 mission statement, "An Agricultural Testament": "Mother earth never attempts to farm without livestock."



For many people, the idea of divorcing beef from a cow or pork from a pig will seem even more unsettling than the controversial yet utterly routine practice of modifying crops with the tools of molecular biology. The Food and Drug Administration currently has before it an application, which has already caused rancorous debate, to engineer salmon with a hormone that will force the fish to grow twice as fast as normal. Clearly, making meat without animals would be a more fundamental departure. How we grow, prepare, and eat our food is a deeply emotional issue, and lab-grown meat raises powerful questions about what most people see as the boundaries of nature and the basic definitions of life. Can something be called chicken or pork if it was born in a flask and produced in a vat? Questions like that have rarely been asked and have never been answered.

Still, the idea itself is not new. On January 17, 1912, the Nobel Prize-winning biologist Alexis Carrel placed tissue from an embryonic chicken heart in a bath of nutrients. He kept it beating in his laboratory, at the Rockefeller Institute, for more than twenty years, demonstrating that it was possible to keep muscle tissue alive outside the body for an extended period. Laboratory meat has also long been the subject of dystopian fantasy and literary imagination. In 1931, Winston Churchill published an essay, "Fifty Years Hence," in which he described what he saw as the inevitable future of food: "We shall escape the absurdity of growing a whole chicken in order to eat the breast or wing." He added, "Synthetic food will, of course, also be used in the future. Nor need the pleasure of the table be banished. . . . The new foods will from the outset be practically indistinguishable from the natural products." The idea has often been touched on in science fiction. In "Neuromancer," William Gibson's 1984 novel, artificial meat—called vat-grown flesh—is sold at lower prices than the meat from living animals. In Margaret Atwood's "Oryx and Crake," published in 2003, "Chickie-Nobs" are engineered to have many breasts and no brains.

Past discussions have largely been theoretical, but our patterns of meat consumption have become increasingly dangerous for both individuals and the planet. According to the United Nations Food and Agriculture Organization, the global livestock industry is responsible for nearly twenty per cent of humanity's greenhouse-gas emissions. That is more than all cars, trains, ships, and planes combined. Cattle consume nearly ten per cent of the world's freshwater resources, and eighty per cent of all farmland is devoted to the production of meat. By 2030, the world will likely consume seventy per cent more meat than it did in 2000. The ecological implications are daunting, and so are the implications for animal welfare: billions of cows, pigs, and chickens spend their entire lives crated, boxed, or force-fed grain in repulsive conditions on factory farms. These animals are born solely to be killed, and between the two events they are treated like interchangeable parts in a machine, as if a chicken were a spark-plug, and a cow a drill bit.

The consequences of eating meat, and our increasing reliance on factory farms, are almost as disturbing for human health. According to a report issued recently by the American Public Health Association, animal waste from industrial farms "often contains pathogens, including antibiotic-resistant bacteria, dust, arsenic, dioxin and other persistent organic pollutants." Seventy per cent of all antibiotics and related drugs consumed in the United States are fed to hogs, poultry, and beef. In most cases, they are used solely to promote growth, and not for any therapeutic reason. By eating animals, humans have exposed themselves to SARS, avian influenza, and AIDS, among many other viruses. The World Health Organization has attributed a third of the world's deaths to the twin epidemics of diabetes and cardiovascular disease, both greatly influenced by excessive consumption of animal fats.

"We have an opportunity to reverse the terribly damaging impact that eating animals has had on our lives and on this planet," Mark Post, a professor in the physiology department at Maastricht University, in the Netherlands, told me. "The goal is to take the meat from one animal and create the volume previously provided by a million animals." Post, who is a vascular biologist and a surgeon, also has a doctorate in pulmonary pharmacology. His area of expertise is angiogenesis—the growth of new blood vessels. Until recently, he had dedicated himself to creating arteries that could replace and repair those in a diseased human heart. Like many of his colleagues, he was reluctant to shift from biomedicine to the meat project. "I am a scientist, and my family always respected me for that," he said. "When I started basically spending my time trying to make the beginning of a hamburger, they would give me a pitiful look, as if to say, You have completely degraded yourself."

We met recently at the Eindhoven University of Technology, where he served on the faculty for years and remains a vice-dean. "First, people ask, 'Why would anyone want to do this?'" he said. "The initial position often seems to be a reflex: nobody will ever eat this meat. But in the end I don't think that will be true. If people visited a slaughterhouse, then visited a lab, they would realize this approach is so much healthier." He added, "I have noticed that when people are exposed to the facts, to the state of the science, and why we need to look for alternatives to what we have now, the opposition is not so intense."

Post, a trim fifty-three-year-old man in rimless glasses and a polo shirt, stressed, too, that scientific advances have been

robust. "If what you want is to grow muscle cells and produce a useful source of animal protein in a lab, well, we can do that today," he said—an assertion echoed by Mironov, in South Carolina, and by many other scientists in the field. To grow ground meat—which accounts for half the meat sold in the United States—one needs essentially to roll sheets of two-dimensional muscle cells together and mold them into food. A steak would be much harder. That's because before scientists can manufacture meat that looks as if it came from a butcher, they will have to design the network of blood vessels and arteries required to ferry nutrients to the cells. Even then, no product with a label that said "Born in cell culture, raised in a vat" would be commercially viable until the costs fall.

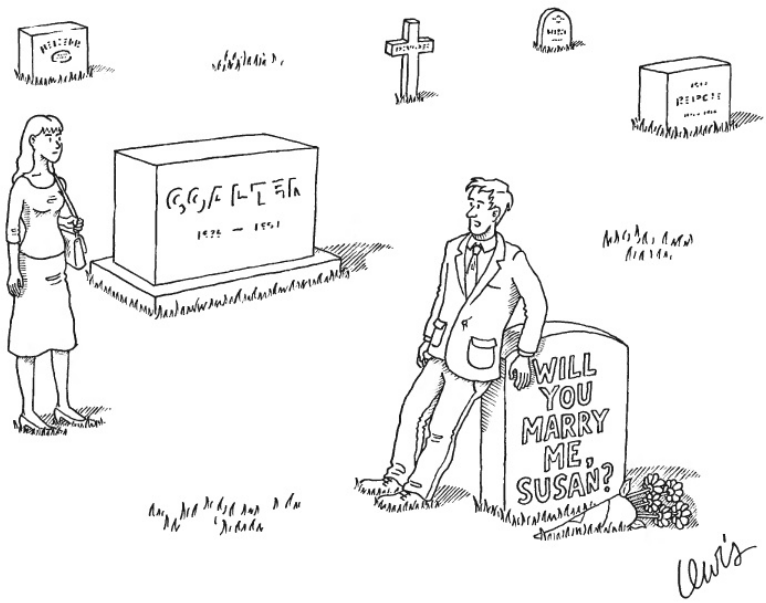
Scientific advances necessarily predate the broad adoption of any technology—often by years. Post points to the first general-purpose computer, Eniac. Built during the Second World War, and designed to calculate artillery-firing ranges, the computer cost millions of dollars and occupied a giant room in the U.S. Army's Ballistic Research Laboratory. "Today, any cell phone or five-dollar watch has a more powerful computer," Post noted. In the late nineteen-eighties, as the Human Genome Project got under way, researchers estimated that sequencing the genome of a single individual would take fifteen years and cost three billion dollars. The same work can now be done in twenty-four hours for about a thousand dollars.

Those numbers will continue to fall as personal genomics becomes more relevant, and, as would be the case with laboratory meat, it will become more relevant if the price keeps falling. "The first hamburger will be incredibly expensive," Post said. "Somebody calculated five thousand dollars. The skills you need to grow a small amount of meat in a laboratory are not necessarily those that would permit you to churn out ground beef by the ton. To do that will require money and public interest. We don't have enough of either right now. That I do not understand, because, while I am no businessman, there certainly seems to be a market out there."

Meat and poultry dominate American agriculture, with sales that exceeded a hundred and fifty billion dollars in 2009. It is unlikely that the industry would cheer on competitors who could directly challenge its profits. Yet, if even a small percentage of customers switched their allegiance from animals to vats, the market would be huge. After all, the world consumes two hundred and eighty-five million tons of meat every year—ninety pounds per person. The global population is expected to rise from seven billion to more than nine billion by the year 2050. This increase will be accompanied by a doubling of the demand for meat and a steep climb in the greenhouse-gas emissions for which animals are responsible. Owing to higher incomes, urbanization, and growing populations—particularly in emerging economies—demand for meat is stronger than it has ever been. In countries like China and India, moving from a heavily plant-based diet to one dominated by meat has become an essential symbol of a middle-class life.

Cultured meat, if it were cheap and plentiful, could dispense with many of these liabilities by providing new sources of protein without inflicting harm on animals or posing health risks to humans. One study, completed last year by researchers at Oxford and the University of Amsterdam, reported that the production of cultured meat could consume roughly half the energy and occupy just two per cent of the land now devoted to the world's meat industry. The greenhouse gases emitted by livestock, now so punishing, would be negligible. The possible health benefits would also be considerable. Eating meat that was engineered rather than taken from an animal might even be good for you. Instead of committing slow suicide by overdosing on saturated fat, we could begin to consume meat infused with omega-3 fatty acids—which have been demonstrated to prevent the type of heart disease caused by animal fats. "I can well envision a scenario where your doctor would prescribe hamburgers rather than prohibit them," Post said. "The science is not simple and there are hurdles that remain. But I have no doubt we will get there."

For at least a century, Eindhoven has been a technical town—first as a base for electronics, then as a center for automobile and truck manufacturing. In the past decade, it has become the capital of the Netherlands' influential industrial-design movement. When I was there, the city was filled with men and women cycling purposefully through the streets, many in dark clothing and angular eyewear. Philips, the Dutch electronics giant, was once based in the center of town, and the company's highly respected design center is still there. As architecture, industrial design, engineering, and biology have become increasingly interrelated, Eindhoven became a natural home




*"Come see who's buried next to your dad."*

for the nation's premier University of Technology. In turn, the university, and particularly its department of biomedical engineering, has become the hub for research into growing meat.

Soon after I arrived, Daisy van der Schaft, a thirty-four-year-old assistant professor, took me to the lab where the meat team conducts most of its experiments. Until recently, she concentrated on regenerative medicine, but in-vitro meat has begun to occupy increasing amounts of her time and imagination. "On the practical level, there was some grant money," she said. "And, on the personal level, this is an opportunity to do something worthwhile. But, for a scientist, it's not that big a switch."

In the past decade, the idea of taking healthy cells from our own bodies and using them to grow replacement parts has moved from a hopeful theory to an increasingly frequent reality. With organ-donor shortages as a powerful incentive, medical researchers have had success in creating whole and partial organs to repair and, in some cases, replace diseased tissues. Scientists have used stem cells to construct windpipes, skin, cartilage, and bone. Biologically engineered bladders have been placed in many patients. (Anthony Atala, the director of the Wake Forest Institute for Regenerative Medicine, described, in a talk he delivered at the TED Conference this March, how he implanted artificially constructed bladders in people who had subsequently been healthy for years. While Atala spoke, in an auditorium in Long Beach, California, a three-dimensional printer was busy in the background, producing the prototype of a kidney. Instead of ink, however, the printer used layers of cells that it then fused together.) In Tokyo, scientists have developed a technique for wrapping a thin sheet of cardiomyocytes—muscle cells that the heart needs in order to beat—around the severely damaged hearts of patients. Once implanted, the sheets, beating independently, act like an extra battery. Such successes have helped spark interest in the meat project, because the skills required to fashion an organ from stem cells are similar to those needed to make minced meat or sausage in a petri dish.

Van der Schaft handed me a starched white coat and pointed to a row of incubators—delivery rooms used by researchers to grow cells and tissues of all kinds. "It's an exciting project," she said as she reached into an incubator and removed one of many small Plexiglas boxes. "A hopeful project." Each box contained six disks filled with muscle cells. The cells, gelatinous brown smears resting between identical Velcro beds filled with nutrients, were nearly impossible to see without a microscope. "This is what I have to show you right now," she said, grimacing. "They did tell you we didn't have meat as such, right?" I had been duly informed. The team learned long ago that visitors feel cheated when they realize that there will be no lunch of faux chicken or vat-ripened pork. Despite the warning, I felt cheated, too.

Nearly every person I told that I was working on this piece asked the same question: What does it taste like? (And the first word most people blurted out to describe their feelings was "Yuck.") Researchers say that taste and texture—fats and salt and varying amounts of protein—can be engineered into lab-grown meat with relative ease. For the moment, taste remains a secondary issue, because, so far, the largest piece of "meat" that has been produced in Eindhoven measured eight millimetres long, two millimetres wide, and four hundred microns thick. It contained millions of cells but was about the size of a contact lens. The specimen I saw was as visually stimulating as mouse droppings, and, if such a substance can be said to look like anything, it looked like a runny egg. How, I wondered, could those blobs ever feed anyone?

Van der Schaft tried to explain. The initial cells are typically taken from a mouse. (The Dutch have also focussed on pork stem cells, because pigs are readily available to them, often reclaimed from eggs discarded at slaughterhouses or taken from biopsies.) Researchers then submerge those cells in amino acids, sugars, and minerals. Generally, that mixture consists of fetal serum taken from calves. Some vegetarians would object even to using two animal cells, and the fetal-calf serum would present a bigger problem still. Partly for those reasons, a team working under Klaas Hellingwerf, a microbial physiologist at the University of Amsterdam, has been developing a different growth medium, one based on algae. After the cells age, van der Schaft and her colleagues place them on biodegradable scaffolds, which help them grow together into muscle tissue. That tissue can then be fused and formed into meat that can be processed as if it were ground beef or pork.

The research is not theoretical, but at this point the Dutch scientists are far more interested in proving that the process will work than in growing meat in commercial quantities. They are preoccupied, in other words, with learning how to make those lens-size blobs more efficiently—not with turning them into

## IN DAYLIGHT, I TURNED ON THE LIGHTS

In daylight, I turned on the lights,
in darkness, I pulled closed the curtains.
And the god of *More*,
whom nothing surprises, softly agreed—
each day, year after year,
the dead were dead one day more completely.
In the places where morels were found,
I looked for morels.
In the houses where love was found,
I looked for love.
If she is vanished, what then was different?
If he is alive, what now is changed?
The pot offers the metal closest to fire for burning.
The water leaves.

—*Jane Hirshfield*

hamburgers or meatballs. Great scientists attempt to change the way we think about the natural world but are less concerned with practicalities. They look upon any less fundamental achievement as "an engineering problem," dull but necessary grunt work. "Scientists hate this type of work, because they want breakthroughs, discoveries," Mironov told me. "This is development, not research. And that is the biggest problem we face."

The Dutch team has been trying to discover how best to work with embryonic stem cells, because their flexibility makes them particularly attractive. Stem cells can multiply so quickly that even a few could eventually produce tons of meat. Yet any culture nutritious enough to feed stem cells will have the same effect on bacteria or fungi—both of which grow much more rapidly. "We need completely sterile conditions," van der Schaft explained. "If you accidentally add a single bacterium to a flask, it will be full in one day." There is also the cancer syndrome: stem cells proliferate rapidly and could divide forever if they are maintained properly. That's why they are so valuable. Yet when a cell divides too often it can introduce errors into its genetic code, and these create chromosomal aberrations that can lead to cancer. Tissue engineers need to keep the cells dividing rapidly enough to grow meat on an industrial scale, but not so fast that they become genetic miscreants.

Any group that intends to sell laboratory meat will need to build bioreactors—factories that can grow cells under pristine conditions. Bioreactors aren't new; beer and yeast are made using similar methods. Still, a "carnery," as Nicholas Genovese, the PETA-supported postdoctoral researcher, has suggested such a factory be called, will need much more careful monitoring than a brewery. Muscle cells growing in a laboratory will clump together into a larger version of the gooey mess I had just seen if they're left on their own. To become muscle fibres, the cells have to grow together in an orderly way. Without blood vessels or arteries, there would be no way to deliver oxygen to muscle cells. And without oxygen or nutrients they would starve.

It turns out that muscle cells also need stimulation, because muscles, whether grown in a dish or attached to the biceps of a weight lifter, need to be used or they will atrophy. Tissue fabricated in labs would have to be stimulated with electrical currents. That happens every day in research facilities like the one at Eindhoven; it is not a difficult task with a piece of flesh the size of a fish egg. But to exercise thousands of pounds of meat with electrical currents could potentially cost more than it's worth.

Technical complexities like these have caused some people to suggest that the field will fizzle before one hamburger is sold. Robert Dennis, a professor of biomedical engineering at the University of North Carolina in Chapel Hill, said that the differences between animal tissue and laboratory-created organs remain significant. "Muscle precursor cells grown in a gelatinous scaffold are really just steak-flavored Jell-O," he said. "To reach something that would have real consumer appeal would require stepping back and approaching the question from a fundamentally new direction." Dennis is no less eager to grow meat than his colleagues. He is, however, concerned about hype and false hope. "Engineering fully functional tissues from cells in a petri dish is a monumental technical challenge, in terms of both difficulty and long-term impact," he said. "It is right up there with the Apollo program; a permanent and sustainable solution to the global energy and food challenges, appreciated by the public but not yet solved; the global freshwater problem, not yet appreciated by the general public; and global climate change, still vehemently denied by the scientific illiterati. Tissue engineering is well worth the investment, because it will profoundly improve the human condition."

Most others engaged in the research say that the goal isn't quite so distant. "There are many practical difficulties that lie ahead," Frank Baaijens told me. Baaijens is a professor at Eindhoven and a leader in the development of cardiovascular tissue. "But they are not fundamental problems. We know how to do most of what we need to do to make ground meat. We need to learn how to scale it all up. I don't think that is a trivial problem, but industries do this sort of thing all the time. What is needed is the money and the will." Baaijens agreed to work on the project only because it was similar to his current research on the debilitating bedsores that occur when sustained pressure cuts off circulation to vulnerable parts of the body. Without adequate blood flow, the affected tissue dies. "This guy approached us and said, 'You ought to make meat,' " Baaijens recalled. The guy was Willem van Eelen. "We had some doubts, because we were focussed on medicine. But he was so enthusiastic and persistent, and, in the end, I think he was right. We don't necessarily think of this as medicine, but it has the potential to be as valuable as any drug."

Stone Barns, a nonprofit farm in Pocantico Hills, north of New York City, is an eighty-acre agricultural wonderland. The animals and plants there rely on each other to provide food, manure, nutrients, and the symbiotic diversity that any sustainable farm requires. I had come to discuss the future of meat with Dan Barber, the celebrity chef at Blue Hill, the culinary centerpiece of the property. Barber has strong views about the future of agriculture, but he disdains the partisan and evangelical approach so often adopted by food activists. He believes that organic farming can provide solutions to both agricultural and ecological problems. He is not willfully blind, however, to the irony of a farmer in the rich world who thinks that way. "To sit in some of the best farming land in America and talk about what organic food could do to solve the problems of nine hundred million people who go to bed hungry every night . . ." He stopped and smiled wanly. "That is really a pretty good definition of élitist."

When I called a few days earlier and told him that I wanted to talk about lab-grown meat, there was silence on the phone. Then laughter. "Well," he said, "I would rather eat a test-tube hamburger than a Perdue chicken. At least with the burger you are going to know the ingredients." Barber said that he would be perfectly willing to taste such a product. Unlike some other environmentalists, however, he was leery about the ecological value. "If we were replacing some factory-farmed animals, then I suppose it could be used as a complement to agriculture. But removing animals from a good ecological farming system is not beneficial." Barber argues that the vast systems of factory farms in the United States rely on almost limitless supplies of clean water and free energy, which permits farmers to

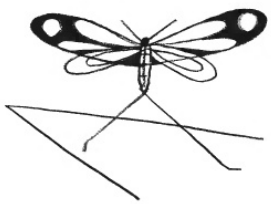
avoid paying a fair price for the carbon used to raise livestock and move their products around the country. Eventually, that will have to change, he says, and, when it does, so will the economics of our entire farm system.

It was the first fresh day of spring, and we went out to watch the heritage sows forage in the natural wilds of the farm. They seemed as happy as any person who had just emerged into sunlight from a particularly difficult winter. "The residual benefits of a natural system like this are cultural," Barber said. "These animals are part of a system in which everything is connected. That is why you have to look at the entire life cycle of farms and animals when talking about greenhouse gases."

Barber disputes the common assertion that livestock eating grass belch huge amounts of methane into the atmosphere and are therefore environmentally unacceptable. "That is a simplistic way to look at this problem," he said. "In nature, you just cannot measure methane and say that livestock contribute that amount to climate change and it is therefore a good idea to get rid of livestock. Look at meat. I am not talking about factory farms—which are terrible—or the need for better sources of protein for many people in the world. But if you just look at meat without looking at the life of a cow you are looking at nothing. Cows increase the diversity and resilience of the grass. That helps biological activity in the soil and that helps trap $CO_2$ from the air. Great soil does that. So when you feed a less methane-emitting animal grain instead of grass you are tying up huge ecosystems into monoculture and plowing and sending enormous amounts of $CO_2$ into the air with the plows. You are also weakening soil structures that might not come back for hundreds of thousands of years." Stressing that he understood that a growing population will need additional sources of protein, he continued, "So if you can supplement a farming system with cultured meat, that is one thing. But if your goal is to improve animal welfare, ecological integrity, and human health, then replacing animals with laboratory products is the wrong way to go."

The moral and ethical issues that would accompany the use of lab-grown beef may ultimately prove more intractable than the scientific issues. In 2008, when PETA announced a million-dollar reward for the first team to make in-vitro chicken, many animal-welfare activists responded with outrage. Jim Thomas, of the environmental group ETC, expressed a common fear: "If test-tube meat hits the big time, we will likely know by its appearance in a Big Mac or when agribusiness buys out the patent-holder." Even some PETA leaders felt that the decision to support research into in-vitro meat was dangerous. Lisa Lange, a PETA senior vice-president, opposed the award. "My main concern is it's our job, as the largest animal-rights organization in the world, to introduce the philosophy and hammer it home that animals are not ours to eat," she said.

I can understand why a chef and farmer like Dan Barber believes that we ought to raise animals, kill them humanely, and eat them. I had trouble, though, comprehending why animal-rights supporters weren't rushing to embrace a plan that could ultimately end the use of livestock. I put the question to Peter Singer, the Princeton philosopher, who, in 1975, published "Animal Liberation," which is often considered the founding document of the animal-rights movement. Singer doesn't come at animal-welfare issues from the perspective of a pet owner; he is a utilitarian and believes that it is our moral duty to reduce the amount of suffering on earth. Since our taste for meat is the only reason that animals are butchered inhumanely and raised in monstrous conditions, he considers eating meat immoral, because it greatly increases the amount of suffering in the world. "It seems all pluses and no minuses to me," he said of in-vitro meat. "But I think some vegetarians and vegans just have a 'yuck' response to meat, whatever its source. Or they think it is unhealthy. Or they think that, if we accept it, people will think that 'the real thing' is better, whereas we have been trying to tell them for years that it isn't.



These are all confusions, in my view. Catholics for centuries taught that masturbation is wrong because sex should lead to procreation. Then I.V.F. comes along, and masturbation is the obvious way to get the sperm that enables an infertile couple to have a child. And the same Catholics say no, masturbation is wrong."

Nobody can yet say whether in-vitro meat would find a market. That will depend on the cost and whether people regard it as safe, healthy, and morally acceptable (or perhaps superior) to what we eat today. The last issue is difficult to address. Americans are big fans of the Food Network, and of cooking shows such as "Top Chef." They are eager to follow recipes, too. "I wonder how people would feel if, at the beginning of a show, the stars pulled a darling little lamb onto the stage and then beheaded, gutted, and skinned it," Ingrid Newkirk said. "I am thinking that the ratings would fall." It may take a sight that shocking for people to fully understand what is at stake. More than anything else, more even than the technical aspects of the science, the success of laboratory-bred meat will depend on our understanding of its importance.

"When I was a kid, I liked to read about science," Bernard Roelen told me. Roelen, a member of the in-vitro-meat research team in the Netherlands, is a stem-cell biologist at Utrecht University. "And often you would read about some problem—nuclear waste, for instance—where it would say we don't know now what the solution is, but scientists will find a solution. And now I am a scientist and we face a really serious issue in the environment. And I feel a responsibility to find an answer.

"Because who will find solutions to these problems? It has to be scientists. We made a mess, and we have to clean it up. I know Willem van Eelen wants to see this happen overnight, and that is not possible. But it will happen eventually, and when it does I think we will look back and wonder why it took so long—why it took so long for us to understand what we have done to animals and to the earth." ♦

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Michael Specter talks about lab meat.