ToughTech

A publication by The Engine, built by MIT

SPRING 2019

03

Where's the Beef?

The Uncertain Future of Food

Waste Not

NEXT STARTS NOW.

To the companies at The Engine, Tough Tech is all about bringing bold, world-changing technologies to life—technologies that will help:

+ Produce steel with zero CO_2 emissions.
+ Store enough renewable energy to power a city.
+ Program quantum computers.
+ Harness the power of silk to keep food fresher.
+ Save massive amounts of energy through nanofiltration.
+ Build chips to power a communication revolution.
+ Program an operating system for biology labs.
+ Build the next generation of ultra-efficient semiconductors.
+ Pioneer a better response system for deadly diseases.
+ Engineer therapeutic cells up to 10,000x faster.
+ Create better medicine using lasers and nanotech.
+ Make autonomous driving safer.
+ Create a digital nose to keep us safe.
+ Turn fusion power into a reality.
+ Unlock the potential of data from space.
+ Deliver medicine with sound.
+ Make medicine and vaccine delivery easier and more effective.

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Spring 2019
The Engine, Built by MIT
Print by Puritan Capital, NH, MA.
Design by www.draft.cl

THE ENGINE
Built by MIT

A home for Tough Tech founders.

The Engine, built by MIT, invests in early-stage companies solving the world's biggest problems through a convergence of breakthrough science, engineering, and leadership.

We accelerate the path to market for Tough Tech companies through a combination of capital, infrastructure, and network.

Tough Tech, defined.

Tough Tech is transformative technology that takes the long view, solving the world's important challenges through the convergence of breakthrough science, engineering, and leadership.

Founders at The Engine work in the fields of:

▲
ADVANCED MANUFACTURING

ENERGY
▼

▲
ADVANCED MATERIALS

FOOD & AGRICULTURE
▼

▲
BIOTECH & LIFE SCIENCES

ROBOTICS
▼

▲
SPACE

SEMICONDUCTORS
▼

▲
QUANTUM COMPUTING

INTERNET OF THINGS
▼

▲
DEEP SOTWARE & AI

...AND THE INTERSECTION OF OTHER NEW TECHNOLOGIES

A NOTE FROM OUR CEO

I am continuously humbled by the vision, tenacity, and capability of Tough Tech founders. Our challenge, to clear a path to commercial success for these founders and their companies, seems trivial compared to the challenges they face. It's awe-inspiring to watch founders simultaneously pioneer a breakthrough technology, manage an ambitious team, and navigate what can be a labyrinthine financial and regulatory environment. So founders, thank you—thank you for what you are bringing to the world, and thank you for showing others that it's possible to turn experimental theory into commercial reality.

The Engine is constantly seeking founders working at the edge of what's possible. Our group of 17 portfolio companies (as of May 2019) is exceptionally diverse. From companies like Commonwealth Fusion Systems, which is pioneering commercial fusion energy, to HyperLight, which is creating a novel breed of electro-optic modulators to help usher in a new age of connectivity—each portfolio company, while distinct, is united by its world-changing potential.

Even with such diversity, The Engine is constantly looking at sectors that hold the promise of bringing humanity something truly new. One of those is food and agriculture. It is a vast and nuanced set of industries that intimately impacts every human being, every day. It is also ripe for Tough Tech innovation.

This publication will focus solely on the world of food and agriculture. Three articles will dive deep into technologies, trends, and people that are changing the world's relationship with its crops and food. The Engine also offers its perspectives on the emerging food and ag landscape in the Boston region, as well as the opportunities and risks inherent in various technological verticals within the sector.

Katie Rae
CEO & Managing Partner

The Future of Food & Ag

The challenges facing the global food and agriculture industry are as personal as they are universal. No matter where you live, the food on tonight's dinner table has most likely been touched by a mix of science, farming, and processing practices spanning continents. For this publication, we have chosen to address three global challenges we see as inspiring the most convergent solutions—those that must be met with a combination of technology, regulation, and societal change.

- *Satisfying the world's increasing appetite for animal protein*
- *Addressing the impact of climate change on the globe's staple crops*
- *Creating a less wasteful and more efficient global food supply chain*

The solutions to these challenges do not exist in isolation. Many are, in fact, codependent (lab-grown meat has the potential to be significantly less wasteful than raising poultry or cattle traditionally, for example). These articles touch upon such codependence, but are intended to explore individual ecosystems of technology and people.

The intimacy of food cannot be ignored—it binds cultural identity and individual experience. Any changes to the food system, especially those that manipulate our actual food, will have to confront millennia of tradition. How will humanity reconcile the need for food and agriculture innovation with its evolutionarily and culturally ingrained tastes and behaviors?

The incentive for such innovation is not purely existential—there is tremendous economic opportunity for those bold enough to attempt to transform humanity's relationship with food and agriculture. Food and agribusiness is a $5 trillion global industry, yet food systems-focused startups have only attracted $14 billion in investment globally in 1,000 startups since 2010.[1] One can contrast this with the global healthcare industry, which is worth a similarly massive $7 trillion, and its 145 billion in investment in 18,000 startups since 2010, to understand the market potential of a true food and agriculture technology revolution.

Such a comparison is made even more compelling by considering that the two sectors benefit from many of the same fundamental breakthroughs in biology, chemistry, and computing (CRISPR can edit the DNA of a tomato or a liver cell, silk proteins can ensure the freshness of a head of lettuce or blood sample, algorithms can optimize harvests and discover new molecules, etc…).

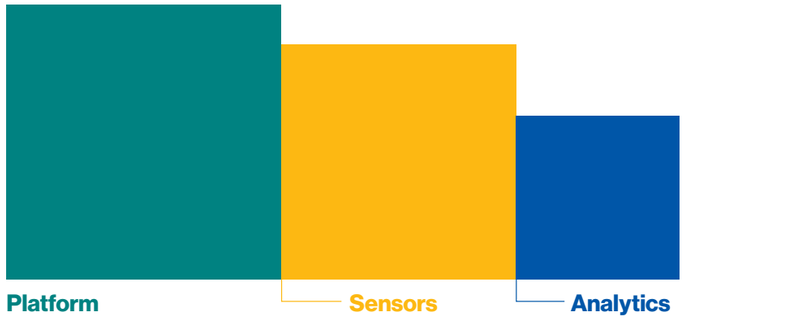
Strain on our food and agriculture systems is real. And it will only become more conspicuous as the globe's population approaches the 10 billion mark sometime around 2050. Technology, particularly Tough Tech with its emphasis on convergent, breakthrough sciences, will play a major role in satisfying an insatiable global appetite for accessible, high-quality, and culturally relevant food.

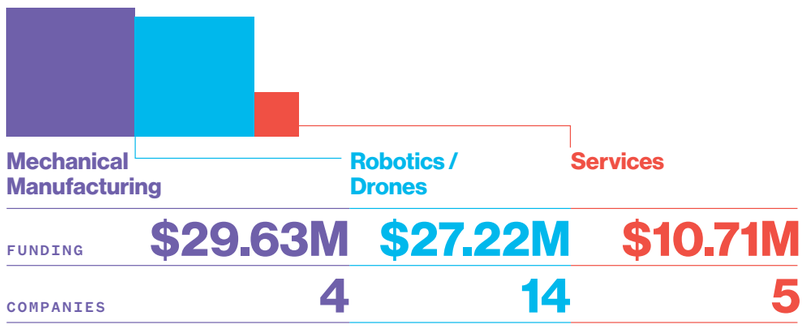
Let's dig in.

|1| Innovation with a Purpose: The role of technology innovation in accelerating food systems transformation; World Economic Forum, January 2018

U.S. Venture Investment in Food and Agriculture, 2014-2018

The food and agriculture sector can be subdivided into categories of technological discipline, including: robotics & drones, sensors, crop & food science, agricultural chemicals/biologics, mechanical & manufacturing, analytics, platforms, synthetic environments, and services.





In total, 53% of the funds invested into these startups support technologies in crop & food science, agricultural chemicals/biologics and synthetic environments. In crop & food science, plant breeding technologies have received the most support from the venture community ($75 million), but DNA editing and gene expression technologies are also gaining momentum. With respect to agricultural chemicals/biologics, most funding ($34 million) is going to firms working with various plant additives, while technologies used to lure insects or enrich soil have received modest support ($4 million and $2 million, respectively).

Venture capital support for companies attempting to expand farming to synthetic environments has also been robust ($79 million). Over this time period, however, various cannabis producers also emerged in response to the national trend toward legalization, which potentially skews the data.

While the food and agriculture sector is technologically diverse, the majority of investments in these companies ($298.2 million) is targeting the same link in the supply chain: harvesting/production. The other components of the supply chain—handling and storage, processing, and distribution—received $7.2 million, under $1 million, and $64.5 million in investment, respectively.

Why is there such a disparity of investment and entrepreneurial activity amongst these segments? Aside from the fundamental importance of producing food, one could argue that startups in the harvesting/production segment lean heavily on technologies advanced in other industrial sectors (genetic engineering or machine learning, for example). Those in the harvesting/production space are not necessarily inventing technology specifically for agricultural applications, but rather find large market opportunities associated with agricultural applications.

As biotech innovation and food and agriculture innovation become more intertwined, and more and more of us become captivated with new modes of food production (who isn't curious about a vegan hamburger that bleeds?), we can logically expect more innovations and investment in the space. But it is important to remember that there is profound opportunity elsewhere in the food and agriculture sector if entrepreneurs and investors are bold enough to seize it.

The Food & Agriculture Ecosystem in New England

New England is fertile ground for innovative food and agriculture companies due, in large part, to the region's intellectual capital and symbiotic advances in biosciences and technology. This map defines the broad ecosystem that's taken root in the region. A comprehensive catalog of private and public companies, investors, government, academic and non-profit initiatives within the segment is featured on page 66.

COMMUNITY BUILDING AND MORE

- Agtech Nexus
- Artscience Culture Lab and Cafe
- Bayer LifeHub Boston
- Bevnet Live
- Branchfood
- Cambridge Food Lab
- FoodEdge
- Global Summit on Agriculture, Food Science and Technology
- New Harvest
- Nutter Uncommon Law
- Revision Urban Farm
- Slow Food
- Sustainable Food Lab
- Target FoodFutureCoLab
- The Food Project
- Urban Farming Institute
- Venture Cafe Cambridge

PRIZES/ACCELERATOR/ INCUBATOR

- Greentown Labs
- Techstars Boston
- Mass Challenge
- Mass Robotics
- MIT 100k
- MIT Sandbox Innovation Program
- MIT Solve
- Rabobank MIT Food and Agribusiness Innovation Prize
- The Food Loft

ACADEMIC INITIATIVES

- Babson College
- Boston College
- Harvard
- MIT
- Tufts
- U Mass Amherst

GOVERNMENT

- City of Boston Food Access Urban Ag Visioning
- Feed The Future
- Agricultural Energy Grant Program (ENER)
- MassCEC grants
- NSF grants
- USDA - NIFA

INVESTOR

$111.08B
AUM

- Alexandria Venture Investors
- Anterra Capital
- BASF Venture Capital
- BioGenerator
- Branch Venture Group
- Breakthrough Energy Ventures
- Flagship Pioneering
- Flybridge Capital Partners
- Fresh Source Capital VC
- GV
- Hancock Agricultural Investment Group
- NEA
- Novo Holdings
- Raptor Group
- Rhapsody Venture Partners
- Romulus Capital
- SOSV
- Spark Capital
- Supply Chain Ventures
- Tabard Venture Capital
- The Engine
- The Fink family Foundation
- Viking Global Investors

PUBLIC COMPANIES

$108.68B
Market Cap

- Bayer
- BGI
- Future Farm Technologies
- Ocean Spray
- Silgan Holdings
- Standex
- Sysco
- Wismettac
- Yield10 Bioscience

PRIVATE COMPANIES

$3.08B
Invested

- Agrivida
- American Robotics
- Analytical Space
- B.Good
- Beantrust
- Bevi
- Biobot Analytics
- Bloom Automation
- C16 Biosciences
- C2Sense
- Cambrian Innovation
- Cambridge Crops
- Chew Innovation
- Cibo Technologies
- Climacell
- Clover Food Products
- Crop Enhancement
- Crop One Holdings
- Drizly
- Emulate
- Enko Chem
- Franklin Robotics
- Freight Farms
- Fresh Nation
- Geovantage
- Ginkgo Bioworks
- Greenlight Biosciences
- GreenSight Agronomics
- Harvest Automation
- Inari Agriculture
- Incredible Foods
- Indigo Agriculture
- InnovaSea Systems
- Joyn Bio
- KnipBio
- Kula Bio
- Liquiglide
- Manus Bio
- Motif Ingredients
- Natural Products Consulting
- Northbound ventures
- One Mighty Mill
- Promethean Power Systems
- Root AI
- Sandymount
- Smart Lunches
- Soft Robotics
- Spoiler Alert
- Spyce
- State Garden
- Stonyfield Farm
- Telluslabs
- Understory
- Yasso

WHERE'S THE BEEF?

The future of protein lies in plant-based and cell-based meat. It's a nascent industry with plenty of challenges, but these innovators won't be cowed.

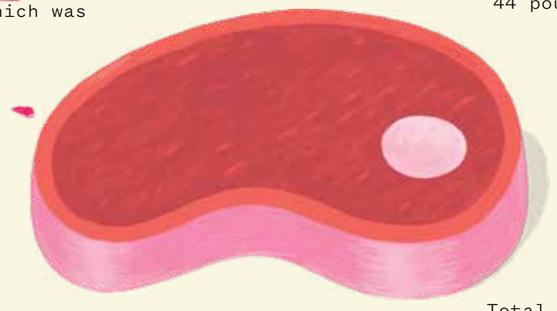
By *Kara Baskin* for *The Engine*
Illustrations by *Gabriel Ebensperger*

The data behind the world's love of animal protein.

In 2017, U.S. meat production totaled **52 billion pounds**– 26.3 billion of which was beef.

Approximately **30 percent** of the calories consumed globally by humans come from meat products.

In the U.S. alone, approximately **95 pounds of meat** per capita have been consumed annually over the last three years, an increase of 44 pounds since 1961.



U.S. consumers spend **more than half** of their protein dollars on animal protein.

One cow can consume up to **30 gallons** of water per day.

Total emissions from global livestock are **7.1 gigatonnes** of CO_2-equivalent per year, representing 14.5 percent of all anthropogenic greenhouse gas emissions.

Cattle raised for beef and milk are the animal species responsiblefor the most emissions, representing **65 percent** of the livestock sector.

eef: It's what's for dinner. This was the phrase coined by the Leo Burnett advertising agency in 1992. It touted beef as an essential part of a healthy American diet, and the ubiquitous slogan is still the motto for the Cattlemen's Beef Board and National Cattlemen's Beef Association.

The phrase has become baked into Americana. And why not? In 2017, U.S. meat production totaled 52 billion pounds—26.3 billion of which was beef.[1] On an international scale, an estimated 30 percent of the calories consumed globally by humans come from meat products. In the U.S., approximately 95 pounds of meat per capita is now consumed annually, an increase of 44 pounds since 1961.[2] U.S. consumers spend more than half of their protein dollars on animal protein.[3]

Clearly, humans want meat. But its production is quickly becoming a global crisis. Sustainability is an issue: One cow alone can consume up to 30 gallons of water per day.[4] Emissions are another worry: Total emissions from global livestock are 7.1 gigatonnes of CO_2-equivalent per year, representing 14.5 percent of all anthropogenic greenhouse gas emissions—that is, emissions resulting from human activity.[5] Cattle raised for beef and milk are the animal species responsible for the most emissions, representing 65 percent of the livestock sector.

"It is the biggest environmental threat that humans have ever faced," says Patrick O. Brown, CEO and founder of the Redwood City, California-based Impossible Foods, which specializes in plant-based meats.

A (Not So) Rare Solution

New companies are grinding away on enviro-conscious, potentially healthier ways to deliver meat: cellular and plant-based meat.

Plant-based is the higher-profile of the two methods, and it's poised to be a $7.5 billion global market by 2025. One of the highest-profile purveyors is Impossible Foods, founded by Brown, a former Stanford University biochemist. Impossible claims to use 87 percent less water, emit 89 percent fewer emissions, and impact 96 percent less land than beef made from cows. Their product is made from soy protein, coconut oil, and sunflower oil, and heme—an iron-containing molecule that makes the Impossible's product smell, taste, and bleed like the real thing.

"The alternative protein space is suddenly booming," says Jonathan McIntyre, CEO of Motif Ingredients, a Boston, Mass.-based startup that specializes in alternative protein ingredients made via fermentation, not animal agriculture.

According to Nielson surveys, nearly half of consumers eat a form of protein with every meal.[6] Dollar sales of plant-based foods and beverages increased 14.7 percent in 2017, and 39 percent of Americans are actively trying to incorporate more plant-based foods into their diets, according to Nielson.[7]

"There is a very strong awareness of both the environmental impacts of the food and agriculture industry and the healthfulness of eating more plant based products," McIntyre says. "These products have been around for a long time in different forms and shapes, but they really appealed to a small audience and the quality of the products were

Clearly, humans want meat. But its production is quickly becoming a global crisis.

Patrick Brown
CEO & Founder,
Impossible Foods

Jonathan Mcintyre
CEO, Motif Ingredients

(1)https://www.meatinstitute.org/index.php?ht=d/sp/i/47465/pid/47465
(2)https://www.ers.usda.gov/amber-waves/2018/june/per-capita-red-meat-and-poultry-dis-appearance-insight into-its-steady-growth/
(3)https://www.nielsen.com/us/en/insights/news/2017/when-it-comes-to-protein-americans-still-flock-to-meat.html
(4) https://beef.unl.edu/amountwatercowsdrink
(5)http://www.fao.org/news/story/en/item/197623/icode/
(6)https://www.nielsen.com/us/en/insights/news/2017/when-it-comes-to-protein-americans-still-flock-to-meat.html
(7)https://www.nielsen.com/us/en/insights/news/2017/plant-based-proteins-are-gaining-dollar-share-among-north-americans.html

really not good enough to appeal to a more mainstream audience."

No more: The Impossible Burger debuted in 2016 and is now available in more than 5,000 restaurants worldwide, including Burger King, and a gluten- and cholesterol-free iteration will debut in grocery stores this year.

"We can expect not just to see more of these products on the shelf, but also to start seeing them shelved in more highly-trafficked sections of the grocery store, including right in the meat aisle. Retailers realized that when they introduced plant-based milk to the refrigerated dairy aisle, right next to cow's milk, it resulted in significant sales growth for that category, so why not follow that same strategy for other plant-based categories like plant-based meat? The easy answer is to merchandise them with similar products," says Alison Rabschnuk, Director of Corporate Engagement at The Good Food Institute (GFI), which provides business support to plant- and cell-based meat companies in Washington, D.C.

"The announcement [in April 2019] that Burger King will start selling a Whopper made from Impossible burgers shows just how ubiquitous these products are becoming. The final hurdle to making plant-based meat as equivalent to animal meat is the price; we predict that these products will become less expensive as the companies achieve economies of scale," she says.

In early May 2019, Beyond Meat, a competitor of Impossible Foods, saw 163% gains on first day of public trading, signaling significant appetite for alternative protein from some of the world's most prominent investors.

"I'm all for the Impossible Burger and plant-based meat. It's fantastic, and I think it's the immediate market. But we've tried to change people's dietary habits for years, and it doesn't work," he says. "So we need to take a step back and say, 'OK, what is it that [consumers] really need, really want? Well, they really want meat. Can we produce it in a different way? So rather than trying to change America and say, 'Everybody's got to be a vegetarian,' let's think about how we deliver and how we grow the meat.'"

As such, his goal is to replicate the tissue structure of meat, growing cow heart muscle on a spinach leaf scaffold, stripped of its plant cells. Scaffolding provides external binding, holding the cells together so that they can grow. No high-tech leaves here; Gaudette gets them from the local grocery store.

So we need to take a step back and say, 'OK, what is it that [consumers] really need, really want? Well, they really want meat. Can we produce it in a different way? So rather than trying to change America and say, 'Everybody's got to be a vegetarian,' let's think about how we deliver and how we grow the meat.'

Alison Rabschnuk
Director of Corporate Engagement, The Good Food Institute

Glenn Gaudette
Professor of Biomedical Engineering, Worcester Polytechnic Institute

Turning Over a New Leaf

Cell-based meat—also known as clean or cell-cultured meat—is a more nascent field, and one that might appeal to a broader carnivorous population.

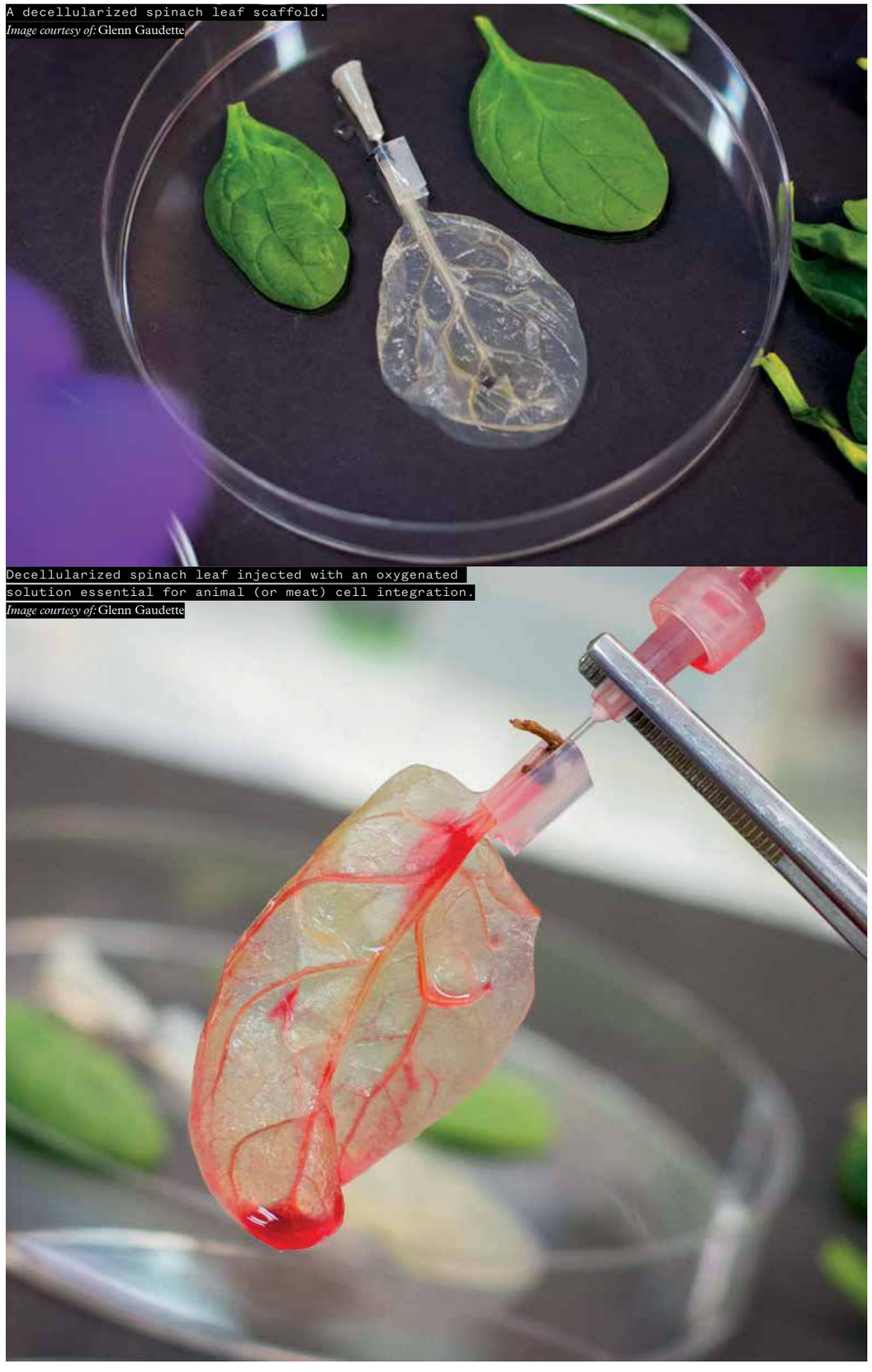
Here, agricultural products are produced from cell cultures. Proponents say that this process will require less land and water than conventional meat, will cause exponentially less climate change, and eliminates the environmental repercussions of animal waste and contamination via runoff. It also requires no antibiotics, produces no bacterial contamination, and won't harm animals.[8]

Worcester Polytechnic Institute biomedical engineer Glenn Gaudette is pioneering the use of edible spinach as a tissue-engineering scaffold to grow cell-based meat. He says that his process is a good alternative for meat-loving consumers who might cringe at the idea of plant-based foods.

Roughly 100,000 bovine cells per leaf are isolated in this process. Gaudette then employs the spinach's natural vasculature to nourish them with an oxygen, protein, and sugar solution. They form long, striated muscle cells.

"Nature has already provided a series of vessels, in the leaf, to deliver water. We can use those vessels to deliver oxygenated solution, putting a tube in the end of the leaf or using pressurized fluid to cause the solution to go through the leaf," he says. "The other big plus is, if you think about growing meat on a scaffold, you want a scaffold that's edible or a scaffold that you could easily get rid of. But a scaffold that's edible and that the consumer is actually familiar with is preferable," he says.

(8)https://www.gfi.org/images/uploads/2017/06/Mapping-Emerging-Industries.pdf



A decellularized spinach leaf scaffold.
Image courtesy of: Glenn Gaudette

Decellularized spinach leaf injected with an oxygenated solution essential for animal (or meat) cell integration.
Image courtesy of: Glenn Gaudette

Ergo grocery store spinach.

In its final form, these cells will transform into what he lovingly terms "mush meats"—hamburger, chicken nuggets, and other such meats easily ground into smaller pieces. However, growing them into a scalable size is a couple of years away, he says. It currently takes months to create a small piece of meat.

"I think if we can get this to work, then in terms of growing different types of meat on the scaffolds, on the leaves, it'll pave the path for other avenues," he says. Ultimately, he hopes to provide decellularized scaffolding to larger cell-based meat companies, who would then grow the cells and customize their health properties, modulating the number of fat and muscle cells involved. This isn't a pipe dream: Mainstream companies such as Tyson Foods have invested in Berkeley, Calif.-based Memphis Meats, which developed the first "clean" meatball in 2016.

Another frontrunner is Motif Ingredients, helmed by McIntyre, a longtime head of research and development at PepsiCo. Motif produces protein through fermentation of engineered microbes. The company launched in February with $90 million in financing.

"It's no different than the way you might make beer," says McIntyre. "You have yeast, or another micro-organism, growing in a tank. We program that micro-organism to produce a protein of interest or an ingredient of interest."

Think of Motif as the secret sauce outsourced to larger food companies who want to mimic a particular flavor and taste. For example, if a company wanted to use a plant-based yogurt with pea protein—but if pea protein lacked that classic, creamy yogurt taste—Motif would in turn develop the proteins to nudge it toward smooth dairy properties.

"You want it thicker? Thinner? Creamier? Tart? We'd be helping to create those ingredients," McIntyre says.

Providing a "Scaffold"

As these techniques grow, organizations are offering them a platform for research and connection.

Cambridge, Mass.-based New Harvest was founded in 2004 to focus on ways to make animal food products using cell cultures instead of whole animals. Today, they fund basic research and cellular agriculture, with an emphasis on research at the university level.

"We fund researchers who are working on different challenges associated with live grown meat, all the way from, 'How do we make a bioreactor that can grow these products?' to 'What kind of cells do we use in that bioreactor and how do we feed those cells?'" says research director Kate Krueger.

Colleagues of New Harvesst include David Kaplan at Tufts University, who is focusing on silk scaffolding. At the University of Auckland, Laura Domigan studies how to feed cells using bovine-serum-free formulations. Marianne Ellis at the University of Bath works on hollow fiber bioreactor production, considered one of the most promising designs for cultured meat. Another researcher is working on nutraceutical food products, wherein molecules grow inside muscle cells, tweaked to produce terpenes. These compounds can have anti-inflammatory, antioxidant, and pain-relieving benefits.

Hypothetically, "You could get the same effect eating a steak chip as you could from having a carrot," Krueger says.

Meanwhile, GFI provides business support services to plant- and cell-based meat companies, advising and providing technical consulting and advice to entrepreneurs in the space. GFI recently funded roughly $5 million in research through their competitive grants program.

Image courtesy of: Motif Ingredients

One conundrum: Is meat really meat, if it's grown in a laboratory? Not surprisingly, the U.S. Cattlemen's Association doesn't think so.

"This is effectively doubling the amount of money that has been invested into these spaces so far, and that's all open-access research," says business analyst Brianna Cameron.

They also work on regulatory policy and with grocery stores to help them understand the plant-based market, in the hopes that they'll stock their shelves with more such brands. Networking opportunities also abound: San Francisco, California-based New Age Meats, a cell-based meat company that focuses on pork sausage, met through a GFI digital community facilitated by Cameron.

"Most consumers are making their food decision based on three factors, and that's price, taste, and convenience. The theory of change that we're trying to work with is if you can get products to compete on all three of those factors, then consumers will have an easier time changing their behaviors than if we're just trying to tell people to change or ask them to change," she says. "Basically, we're trying to create an environment where the better choice is the default choice and where these options are widely available for consumers. They're cost-competitive. They taste just as good. That's our vision of the future."

And the future may be now, or at least soon: Memphis Meats, for instance, plans to bring its first products to market within the next two years, as does Motif.

Is the Cattle Industry Out for Blood?

Of course, not everyone is delighted about these advances, namely the cattle industry.

One conundrum: Is meat really meat, if it's grown in a laboratory? Not surprisingly, the U.S. Cattlemen's Association doesn't think so.

In 2018, the Association sent a petition to the USDA to impose strict labeling requirements on beef: the tissue or flesh of cattle born, raised, and harvested in a traditional manner, rather than coming from alternative sources such as a synthetic product from plant, insects, or non-animal components, or grown from animal cells.[9]

In 2018, Missouri passed a law that prohibits products such as plant-based and cellular meat from calling themselves "meat" at all. There's a tough penalty, including up to one year in prison and up to $1,000 in fines.[10] (Plant-based companies promptly sued.)[11] States such as Iowa and Nebraska are pondering similar laws. The issue mirrors an ongoing struggle in the dairy industry, as the National Milk Producers Federation has continually urged the FDA to crack down on soy and almond products labeled as dairy, with limited success.

This has raised a philosophical conundrum. Where does meat end and science fiction begin? Organizations such as GFI have fired back, accusing the Cattlemen's proposal of impinging on the First Amendment rights of plant-based and cell-based companies and asking for preferential treatment in labeling. After all, the thinking goes, the USDA exists to regulate labels to protect the welfare of consumers, not to favor one production method of meat over another. And what is the "traditional manner," anyway?

There is also the not insignificant issue of public perception. "Cell-based meat" doesn't exactly have a mouthwatering ring, although it's the preferred terminology in the industry. (GFI's Cameron says that "clean meat" is emotionally charged, and "cultured meat" might get confused with cultured food like kimchi.)

Plus, meat is still as American as apple pie. According to Nielsen, 47 percent of consumers believe that unprocessed meat is good for your health.[12] Thirty-four percent believe that those who avoid animal protein are deficient in certain nutrients, and 30 percent believe that animal protein is associated with positive health effects.

There is a misperception that the new modes of meat production aren't natural, says Paul Shapiro, a founder of Sacramento, California-based Better Meat Co. Better Meat was founded in 2018 to make traditional meat healthier. They sell plant-protein blends to major meat-users, which

Kate Krueger
Research Director,
New Harvest

Brianna Cameron
Innovation Manager,
The Good Food Institute

(9)http://www.uscattlemen.org/Templates/pdfs_USCA/2018-PDFs/2-9-18USCA-AMS-Petition-re-definition-of-beef-and-meat.pdf
(10)https://aldf.org/article/missouri-passes-unconstitutional-law-restricting-the-marketing-of-alternative-meat-products/
(11)https://www.nytimes.com/2018/08/28/us/missouri-meat-law-tofurky.html?login=smartlock&auth=login-smartlock
(12)https://www.nielsen.com/us/en/insights/news/2017/when-it-comes-to-protein-americans-still-flock-to-meat.html

Paul Shapiro
CEO & Co-founder,
The Better Meat Co.

Robert Chiles
Assistant Professor in the College of Agricultural Sciences, Penn State University

are mixed into their products so that they use substantially less traditional meat—up to 50 percent, depending on the application.

"The misperception is that this is somehow less natural than many of the other things that we do in our lives. The fact is, meat today is not natural. You think about chickens who have been selectively bred through intensive genetics programs to grow so big, so fast, that many of them have difficulty even walking before they collapse," Shapiro says. "When we think about just how unnatural and unsustainable our current methods of meat production are, this seems like a naturally preferable option."

However, cell-based agriculture is a pre-revenue industry. While plant-based companies have existed on the market for years, cell-based meat still maintains an aura of improbability, as does its technology.

For example, bioreators—10,000-liter vats with a stirring arm in the center—are useful for growing a large mass of cells. These are already commercialized, explains GFI's Cameron. But what happens once cells hit the scaffold (spinach or otherwise)? They need to differentiate into fat cells and muscle cells to form a tissue structure. To do this, a perfusion bioreactor is necessary, and large-scale perfusion bioreactors aren't available yet.

"The size right now is for biomedical applications, such as making one heart valve at a time," Cameron says.

The problem, says Krueger, is that food science is simply lower-tech than cellular agriculture more generally.

"The tech behind cellular agriculture is the same as that of biologics production or tissue engineering, but with different market pressures applied: The tissues generated are simpler than a tissue-engineered organ or a cancer biologic, but the price point must be lower to compete with food prices. While modern food science is pretty amazing, it's much lower-tech than cellular agriculture. If most food scientists want meat, they harvest it from a cow; if they want a plant-based burger, they mash plants to form a burger. For the most part, they are ill-equipped for the technical challenges of maintaining a cell culture facility or running a tissue maturation bioreactor," says Krueger.

The tech behind cellular agriculture is the same as that of biologics production or tissue engineering, but with different market pressures applied: The tissues generated are simpler than a tissue-engineered organ or a cancer biologic, but the price point must be lower to compete with food prices.

There are also ethical considerations, such as the marginalization of farmers, says Robert M. Chiles, who studies agricultural ethics at Pennsylvania State University.

"There's ethical, nutritional, economic, and medical scientific advantages that would be missed by not taking advantage of the promise of these technologies, on the one hand," says Chiles. "On the other hand, I would say that the risk of the technologies becoming successful and becoming more widespread and becoming more widely adopted by consumers is that they further stoke urban, rural, economic misalignment; that they further squeeze small farmers."

He points to San Francisco, California-based JUST Foods as an example of forward-thinking collaboration. They're partnering with a Kobe beef producer in Japan on a cell-based beef product.

"Kobe beef is one of the most prohibitively expensive cuts of meat that you could get anywhere in the world. They're partnering with this farm, and they're saying, 'Hey, let's work together. Let's make your product more accessible. Let's partner between the farmers who have that expertise, they know how to raise the animals, with these startups who are really capitalizing on these new breakthrough technologies in IT and biochemistry.' How can they work together and do something that they couldn't have done by themselves?" he says.

Brown, CEO of Impossible Foods, says his company is exploring ways of repurposing some of the infrastructure used to produce meat in the United States and leveraging it for his production system, so that any new jobs created could support those communities. But the environment takes precedence, he says.

"When you invent an LED light bulb, you're not attacking coal miners. You're just trying to solve a big problem in the world, and wishing no ill will toward the people who are making a living in the old industry," he says.

New research in the journal Frontiers for Sustainable Food Systems explores whether meat grown in a lab could actually accelerate climate change more than traditional meat production, due to laboratories emitting carbon dioxide.

"It's a dilemma, but the greater good is to save the planet from a complete catastrophe by finding a better way to produce these foods. That's priority number one."

However, recent studies have questioned whether cell-based meat is actually better for the environment. New research in the journal Frontiers for Sustainable Food Systems explores whether meat grown in a lab could actually accelerate climate change more than traditional meat production, due to laboratories emitting carbon dioxide.[13]

"We don't really have meaningful numbers exactly other than predictions for really how much better for the environment these products are," says Krueger. "There's some really great life-cycle analyses that have been done by Dr. Hanna Tuomisto at University of Helsinki, which give you a sense for how much better potentially lab-grown meat and cultured meat products could be for the environment, but those haven't yet been able to be validated with real numbers just because production hasn't been scaled yet."

That's the other thing: So far, cell-based meat involves test-sized, inedible scaffolds the size of a pencil eraser. How does this stuff taste?

"We hear reports here and there, but not officially," says Krueger, laughing. "We certainly do not recommend that anyone eat anything that comes out of the lab, because there's all sorts of concerns with that."

Funding at the university level is also a hurdle.

"We like to say it's about a ten-year time horizon," says Krueger. "We think that number could change a lot depending on the status of publicly available funding for cellular agriculture. Right now, cellular agriculture exists in a no-man's-land funding gap, a little bit between the farming area and the biomedical research area. Neither of these groups are very keen yet on funding that research," she says.

The prohibitive cost of bovine serum is another issue. Currently, says Krueger, prices can reach $500 for a 500-milliliter bottle. Because of this, it's difficult to scale lab-grown meat and to prove out its environmental benefits, she says. The proof of concept is there, but production needs to be ironed out, no pun intended. Gaudette, for his part, is searching for ways to grow his cells without using fetal bovine serum—which, of course, still requires cows.

The Bleeding Edge of Innovation

While it might be years before you bite into a cell-based burger, regulatory adjustments are already afoot. In early 2019, the USDA and FDA announced a formal agreement to regulate cell-cultured food products from cell lines of livestock and poultry.[14] The agencies will collaborate to regulate the development and entry of cellular food into commerce, ensuring that they're produced and labeled properly.

And as the growth process is perfected, some say it might even be possible to replicate the process at home, just like baking bread.

"Could everybody have one of their own little mini incubators? 'Gee, I want chicken next week, let me start growing it today.' Plug it in. I think there's opportunities for different types of food. You want 50 percent pork, 10 percent chicken, 40 percent turkey? OK, we can do that," Gaudette says.

Plus, "Once this reaches full scale, we could do a lot more vertical farming—essentially growing vegetables with minimum, usually zero, soil. This allows them to essentially grow on shelves. You could imagine a growing spinach on floors one through five; lettuce on floors five through eight, et cetera. Essentially, we could turn a skyscraper into a farm," he says.

Skyscraper farms sound like a far more appetizing proposition than the term "cell-based meat." That phrase will possibly morph to reflect something more innovative and customized, though.

"Rather than thinking of this as something that's maybe scary or less delicious than available products, think about all the magic that could be in these new products," says Krueger. "Instead of this topping out at something similar to current meat products, we can actually innovate and make something more delicious, more nutritious, more interesting, and valuable than what we currently have."

Take it from Impossible Foods: Natural evolution is no match for technology.

"The big advantage we have is that we're learning more and getting better at what we do every single day, and the cow is not. Animals as a technology haven't fundamentally improved in millennia, and we're getting better every single day," Brown says. "We're very close in competing for the meat-loving customer, and we're passing the cow like a bullet." +

(13)https://www.vox.com/future-perfect/2019/2/22/18235189/lab-grown-meat-cultured-environment-climate-change
(14)https://www.usda.gov/media/press-releases/2019/03/07/usda-and-fda-announce-formal-agreement-regulate-cell-cultured-food

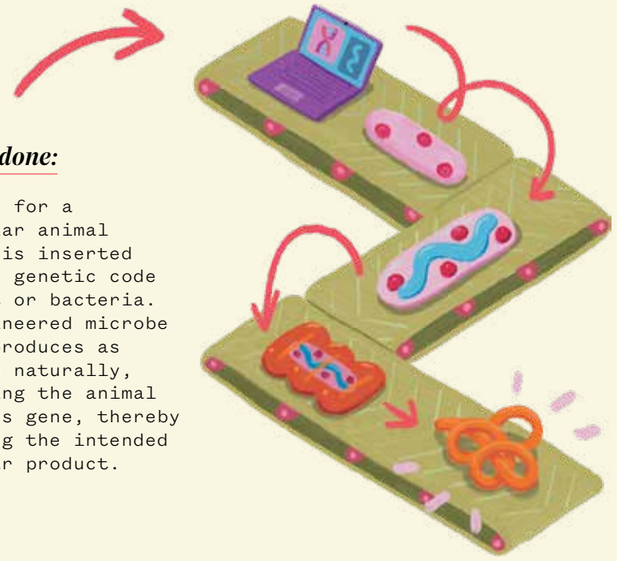
Alternative Protein Technology

Cellular agriculture is the production of agricultural products from cell cultures. Products harvested from cell cultures are exactly the same as those harvested from an animal or a plant; the only difference is how they are made.

Acellular products

How it's done:

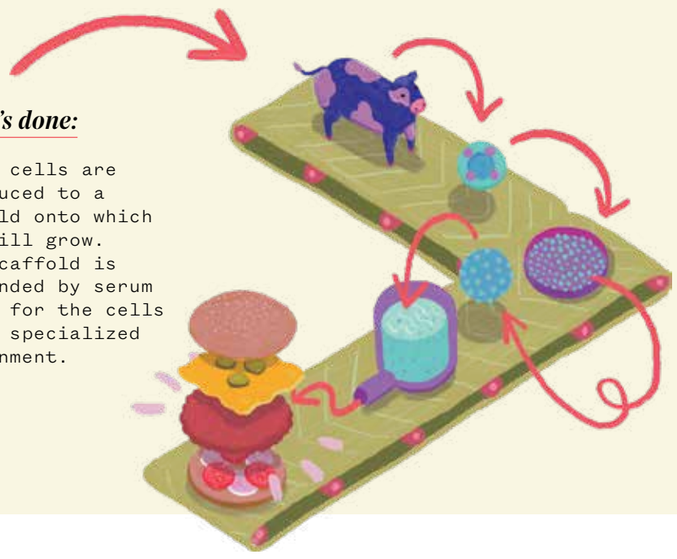
The gene for a particular animal product is inserted into the genetic code of yeast or bacteria. The engineered microbe then reproduces as it would naturally, expressing the animal product's gene, thereby producing the intended acellular product.



Cellular products

How it's done:

Animal cells are introduced to a scaffold onto which they will grow. This scaffold is surrounded by serum — food for the cells — in a specialized environment.



Source: *cellular agriculture definition and data, https://www.new-harvest.org/cellular_agriculture*

Meat & Animal Protein Analogs

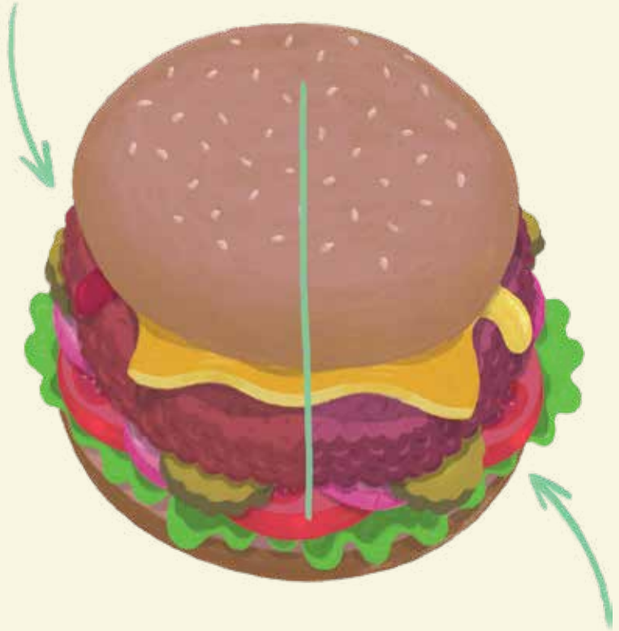
Plant-based protein sources that can be prepared to generally mimic textures and flavors of some types of meat and other animal-based food products.

Meat Analog

Products that are specially created to look, taste, and cook like meat.

Impossible™ Burger

Made from a mixture of wheat protein, coconut oil, and other ingredients including heme from genetically modified yeast. Plant-based heme simulates the animal-based heme in blood that gives meat its distinct flavor when cooked.



Beyond Meat®

Mixtures of pea protein, plant oils, vegetable juices, and more are used to simulate the texture and color of beef or pork sausage.

Animal Protein Analog

These foods may serve as meat or animal protein substitutes, but also have unique flavor and texture profiles in their own right.

Textured Vegetable Protein (TVP)

Tempeh

Seitan

Tofu

"Veggie" Burgers

Plant-Based "Dairy" Products

THE UNCERTAIN FUTURE OF FOOD

Growing Better Food with GMOs, Germs, and Gigabytes

By *Lindsay Brownell* for *The Engine*
Illustrations by *Julie Carles*

or the 55% of humans who live in cities, it can be easy to forget just how much of our planet is dedicated to agriculture. More than one-third of all the land on Earth is used to raise the food we eat, and of that, an area nearly the size of Australia is dedicated to growing cereal crops alone. As a species, we are nearly completely dependent on plants for our survival, which are in turn at the mercy of their environment—too much rain, too little sun, too many insects, or the arrival of a new virus can wipe out an entire harvest.

While plants have evolved strategies to cope with those threats (waxy leaves, sticky sap, commensal relationships with fungi, etc.), humanity, for millennia, has also been coaxing them to develop traits that are more appealing to its needs. Selectively breeding plants with desirable qualities together gave us the starchy, calorie-rich staple crops we eat today. The birth of the field of genetics in the mid-20th century allowed scientists to transfer genes from one organism into another, leading to the creation of the first genetically modified organisms (GMOs) in the 1980s. "Transgenic" GMO plants have since flourished in the face of challenges like pests, weeds, and environmental stressors, and have become the backbone of the modern agriculture industry. Today, the next generation of plant scientists is using new gene editing technologies like CRISPR to modify the genes of food crops directly, allowing them to enhance plants' innate abilities with even greater precision.

Some say that CRISPR crops have arrived just in time, as decreasing yields, a changing climate, declining soil quality, environmental degradation, and growing resistance to pesticides and herbicides are all straining the agriculture industry's ability to meet the global demand for food, not only now, but for the future. Our food production needs to double by 2050 to accommodate a projected global population of 10 billion. Editing the genomes of plants so that they can grow taller, produce more food, use less water, and resist pathogens, while reducing the impact of agriculture on the environment, could be the answer to preventing widespread human suffering and starvation.

Our food production needs to double by 2050 to accommodate a projected global population of 10 billion. Editing the genomes of plants so that they can grow taller, produce more food, use less water, and resist pathogens, while reducing the impact of agriculture on the environment, could be the answer to preventing widespread human suffering and starvation.

The wide-scale adoption of genetically modified crops needed to achieve that vision is not without its challenges, however. GMO plants are currently subject to a patchwork of regulations that differ from country to country, and the rigorous process of getting a new GMO crop approved can last over a decade and cost tens of millions of dollars. Public opinion of GMOs is also not as positive as the industry would like, and consumer preference for non-GMO options is growing.

Despite these challenges, a new crop of agriculture technology companies and research efforts, encouraged by a newly relaxed US ruling on the regulation of CRISPR-edited plants, has sprung up in the last decade. Armed with gene editing, biological-based technologies, and digital tools, they aim to bring the ancient science of agriculture into the twenty-first century, saving our species and our planet in the process.

A Tale of Transgenics

The vast majority of the seeds planted on commercial farms today are GMOs. More than 90% of the corn, soybeans, cotton, sugar beets, and canola grown in the US has been genetically modified in some way,[1] and the worldwide market for GMOs is estimated to surpass $36 billion by 2022.[2] Even if you don't eat corn or beets regularly, it's likely that nearly everything you've consumed today was produced, in some form, from GMOs. The corn syrup that sweetened your muffin or cereal was likely made from Roundup Ready corn, which contains a gene isolated from a bacterium that allows it to survive if sprayed with the herbicide Roundup. The soy lecithin that kept the oils in your afternoon chocolate bar from separating and made your pizza dough fluffy was probably produced from Bt soybeans, which have been engineered to produce a protein that is toxic to certain kinds of insect pests. And GMO corn and soybeans make up the majority of grains that are refined into cooking oils and fed to chickens, cows, and pigs.

In addition to the beneficial traits that allow them to survive better and produce more food, GMO crops have effectively become the industry standard because it takes only about ten years to develop a new GMO plant—compare that to the thousands of years of trial-and-error our ancestors needed to convert an ancient tall grass with small, hard, black seeds into the sweet, starchy, kernel-packed plant we know today as corn. Each of the countless iterations of breeding plants with

Image courtesy of: Bayer

slightly more edible seeds together was effectively a roll of Nature's dice, with the hope that it would produce offspring with the desired traits.[3]

This slow and inefficient "selective breeding" process remained our only way of changing our foods to better serve us through the turn of the 20th century, when it was discovered that radiation caused spontaneous, unexpected changes in living organisms. Starting in the 1920s, scientists bombarded thousands of different plants with x-rays to see what kinds of new traits arose, and many of the resulting mutant varieties are still grown today, like the Rio Red grapefruit, which remains one of the most popular versions of the fruit.[4] But plant breeders still had no way to predict or control what the results of radiation would be—whether a mutation made a plant more appealing or killed it was still up to Nature's dice, albeit they were now rolling faster.

Advances in breeding multiple varieties of plants together led to the creation of hardier and more productive "hybrid" crops in the 1960s, which are credited with enabling the Green Revolution that allowed the planet to more than triple its grain production in just two decades. The process of creating these hybrids, however, was still labor-intensive and subject to the whims of genetics.

In the early 1980s, it was discovered that the microbe *Agrobacterium tumefaciens* could inject a small portion of its own DNA through plants' thick and highly impermeable cell walls and integrate into its host's genome. Scientists could thus use Agrobacterium as a kind of delivery service to introduce a gene for a desired trait into a plant, whose offspring could also inherit the gene. The first "transgenic" plant was created this way in 1983, when an embryonic tobacco plant was infected with Agrobacterium carrying an antibiotic resistance gene originally found in bacteria. Later tests confirmed that the adult plant was antibiotic-resistant.[5] The age of GMO crops had begun.

GMOs: Friends or Foes?

The first genetically modified food crop was introduced to the market in 1994, and over the following two decades the global acreage of GMO crops jumped from 27.5 million acres to an astonishing 448 million as farmers eagerly bought and planted transgenic crops with traits like pesticide and herbicide resistance, improved nutritional value, and tolerance to environmental stressors like drought, frost, and high soil salinity. Beyond their dominance of agriculture in the US, GMOs now account for 95% of the cotton grown in India, over 90% of the soybeans in Brazil and Argentina, and 95% of the canola produced in Canada. These crops are attractive to growers because they help both increase the amount of food they can produce and lower production costs.[6]

Roundup Ready crops, produced by Bayer Crop Science (formerly Monsanto), are one of the most widespread GMOs grown on the planet. Their genetically induced immunity to Roundup allows farmers to simply spray their fields with the herbicide to kill any unwanted weeds rather than tilling the soil to control weed growth. No-till farming also reduces soil erosion and chemical run-off from fields, helping to reduce environmental

(1)http://fortune.com/2014/06/26/monsanto-gmo-crops/
(2)https://www.transparencymarketresearch.com/gmo-crops-seeds-market.html
(3) https://geneticliteracyproject.org/2neered-crops-less-safe-than-classically-bred-food/
(4)https://www.researchgate.net/publication/263596266_The_Origins_of_Red_Pigmented_Grapefruits_and_the_Development_of_New_Varieties
(5)http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1006&context=planthealthdoc
(6)https://www.canr.msu.edu/news/why-many-growers-are-quick-to-adopt-genetic-modification-technology

Michael Raab
Founder & President,
Agrivida

impact. Another popular GMO variety, Bt crops' endogenous production of bacterial Bt toxin protects plants from insect damage and reduces the use of pesticides, which also lowers cost.

In addition to providing protection against external threats, GMOs can also enhance the quality of crops themselves. GRAINZYME Phytase, a type of GMO corn made by Boston-based Agrivida, has been engineered to produce the enzyme phytase within its kernels. Phytase is usually added to animal feed to help pigs, chickens, and cows break down the phytic acid present in grains to extract phosphate and maximize their nutrition. "Phytic acid is actually an 'anti-nutrient,' in that it binds to other things in the grain and makes them less available to the animals. With our GRAINZYME system, we see that animal performance improves beyond what we would expect if we simply gave them phosphate," says Michael Raab, Agrivida's president.

All existing GMOs are created through the insertion of a "foreign" gene from one type of organism into another. Because such an organism could not have arisen naturally, governments around the world require that any new GMOs be put through a regulatory process to demonstrate that the new gene does not have any deleterious effects on the plant or on humans before they can be put on the market.

Different countries have different levels of stringency for GMOs. India has only approved GMO cotton, while Australia permits GMO cotton, canola, and safflower to be grown, but no food crops. The EU has had a de facto ban on the sale of foods produced from GMOs since 2001, but has left it up to its member states to decide whether to plant GMOs on their land (though the EU imports millions of tons of GMO crops every year for livestock feed and other uses). Even in the US, which has one of the most lenient GMO policies, the process to develop a new GMO can take up to twelve years and cost upwards of $130 million.(7) That expense means that only a few companies—namely Bayer, DowDuPont (to become Corteva Agriscience), and Syngenta (owned by ChemChina)—have the means to create new GMOs on a global scale. Some argue that as a result, the agriculture industry has essentially become an oligopoly in which competition is stifled and farmers are locked into buying more expensive GMO seeds to keep up with the demands of a commodity market, which puts small growers and would-be innovators out of business.

As well as these regulatory challenges, GMOs have a notoriously bad reputation among the public and in the media. In an era when consumers are increasingly demanding products that are "natural," many people see plants that are developed in a lab as inherently artificial and possibly even dangerous. 39% of Americans believe that GMOs are worse for their health than non-GMOs (though there is no scientific evidence of any difference), and this large minority is fueling a growing market for non-GMO products. Global sales of more than 50,000 products verified as "Non-GMO" by the advocacy group The Non-GMO Project(8) jumped from $348.8 million in 2010 to $10 billion in 2015.(9) Even GMOs that are developed for humanitarian reasons have endured a backlash: Golden Rice, a strain of rice that produces vitamin A as a way to combat childhood blindness in resource-poor countries, has been stuck in regulatory limbo for nearly two decades, and in 2013 a group of angry protesters stormed a test field where the crop was growing in the Philippines and ripped the plants out of the ground.(10)

(7)https://croplife.org/wp-content/uploads/2014/04/Getting-a-Biotech-Crop-to-Market-Phillips-McDougall-Study.pdf
(8)https://www.nongmoproject.org/about/
(9)http://www.naturalproductsinsider.com/articles/2015/06/removing-gmos.aspx
(10) https://www.nytimes.com/2013/08/25/sunday-review/golden-rice-lifesaver.html?pagewanted=all&_r=1&

A Brief History of Modified Food

Sources page 35.

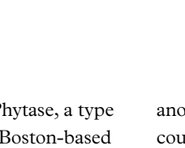
BREEDING | GENETIC MODIFICATION | GENE EDITING

Methods: *Agrobacterium tumefaciens, gene gun*

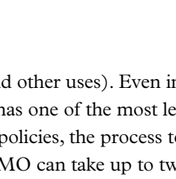
Methods: *TALEN, ZFN, CRISPR* *Not yet on market*

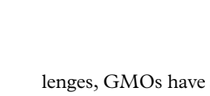
10,000 years ago — **1,000** years ago — **1980** US allows patenting genetically engineered organisms — **1994** Flavr Savr tomatoes first marketed genetically modified food crop — **1996** Roundup Ready Soybean & Bt corn on the market — **2013** seminal CRISPR papers published by Feng Zhang lab — **2016** USDA decides not to regulate CRISPR-edited mushroom

Modern rice emerges • 7000 years ago



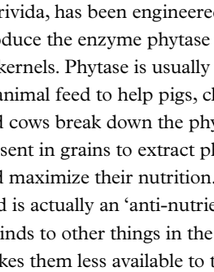
Flavr Savr tomatoes
1981* — 1994

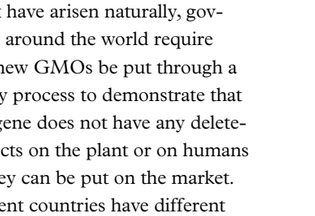




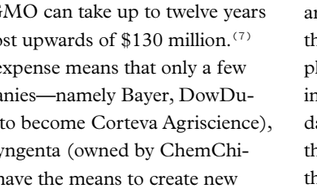
Non-browning mushroom
2013† — Now

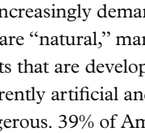
Modern corn emerges • 4500 years ago



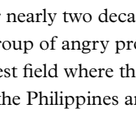


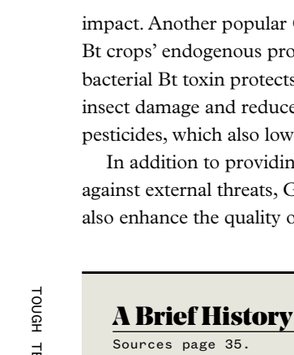
Roundup Ready soybean
1983* — 1996



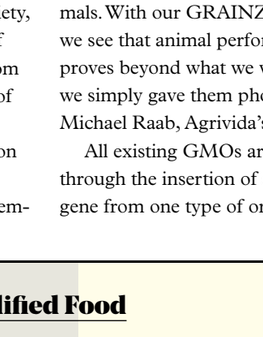


DuPont CRISPR corn
2013† — Now

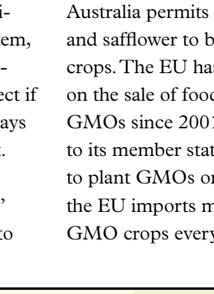




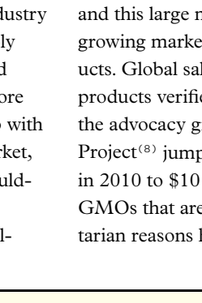
• 9000 years ago



Modern soybean emerges



Bt corn
1983* — 1996

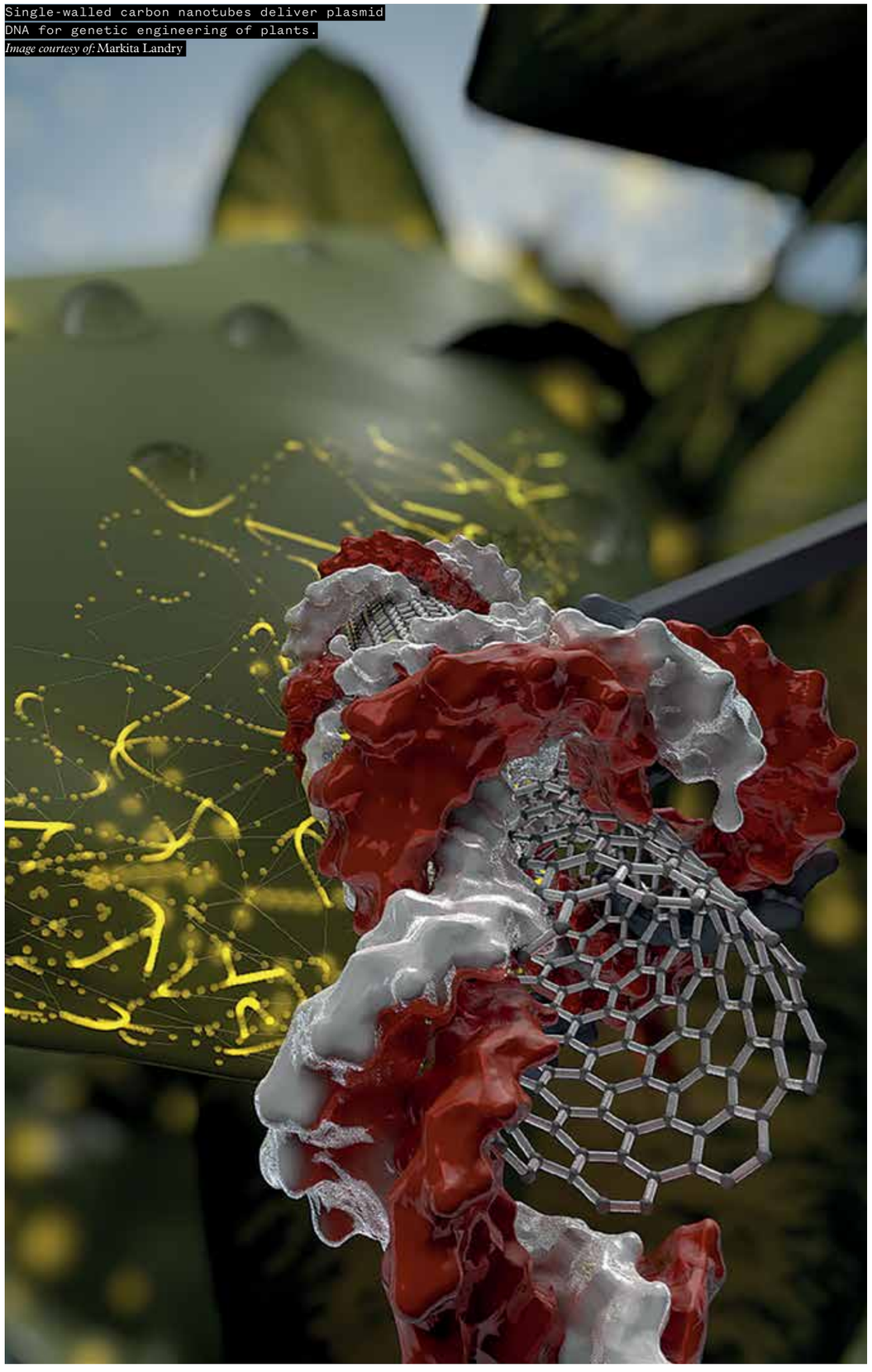


Pairwise corn, soybeans, etc.
2018 — Now

* (note that these start dates are estimates based on the average of years to market)

† (these start dates are an estimate based on when the seminal CRISPR papers appeared)

GMO Classification	US	EU
BREEDING	○	○
GENETIC MODITICATION	●	●
GENE EDITING	○	●



Single-walled carbon nanotubes deliver plasmid DNA for genetic engineering of plants.
Image courtesy of: Markita Landry

Non-GMO GMOs

Plants produced through selective breeding are considered "natural" varietals and skip the GMO regulatory pathway in most countries, so many companies are eschewing GMOs in favor of optimizing selective breeding to produce better plants. Bayer, for example, has an active "marker-assisted breeding" program, which takes DNA samples of thousands of different strains of plants to analyze their genetics as well as their physical traits, which it then uses to select the best candidates for cross-breeding.

Proponents of genetic modification have continued to improve upon the *Agrobacterium* gene-transfer method. In the '90s and early '00s, technologies to edit organisms' genomes were developed, including zinc finger nucleases (ZFNs) and transcription activator-like effector nucleases (TALENs), but these technologies could not meet the throughput demands for commercial-scale agriculture. Then, in 2012, the now-famous CRISPR (short for "clustered regularly interspaced short palindromic repeats") gene editing technology was announced, which provides a much easier and cheaper way to make precise genetic changes. As a result, editing crops' genes suddenly became feasible. And, unlike earlier genetic modification methods used in crops, CRISPR can edit the genome of any plant to a high degree of accuracy without introducing foreign DNA.

The concept of CRISPR has often been compared to a molecular pair of scissors that cuts DNA at a very specific place. The enzyme Cas9, first isolated from bacteria, is the cutting portion of the scissors, which can be "loaded" with a molecule of RNA that is engineered to match a known sequence of DNA in a given organism. When the loaded enzyme is introduced into a host cell, the RNA molecule then guides it to that genetic sequence, and Cas9 cuts both DNA strands. The cell's natural genetic repair mechanism recognizes the cut and joins the strands back together. This process is error-prone and often introduces a mutation that can change or disable a gene located at the target sequence. If scientists want to introduce a new, heavily modified version of the native genetic sequence, they can include a template strand of DNA along with the Cas9-RNA complex, which the cell can incorporate into the genome at the cut point.

CRISPR offers another significant advantage over existing GMOs—the US Department of Agriculture (USDA) announced in early 2018 that it would not regulate any plants modified with gene editing technologies as GMOs, because the genetic changes produced by those methods could conceivably have arisen through traditional breeding or random mutation. This means that, ironically, plants whose genomes are edited using CRISPR can be labeled as non-GMO, and can thus be sold at a higher price to consumers who are willing to pay for that designation. The decision also releases crop developers from the lengthy and expensive GMO regulatory process, which some think has the potential to "democratize" the agriculture industry, as smaller companies and startups without the infrastructure of a Bayer or DuPont can much more readily afford to develop gene-edited plants.

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Markita Landry
Assistant Professor of Chemical and Biomolecular Engineering, University of California, Berkeley

Scott Knight
Head of Genome Editing and Yield, Bayer Crop Science

"CRISPR is going to be a huge key player in…pretty much any biological science where your goal is to edit DNA," says Markita Landry, an Assistant Professor of Chemical and Biomolecular Engineering at the University of California, Berkeley. Her lab is working on ways to enable CRISPR and other gene editing technologies to reach their full potential by helping them get past the problem of the plant cell wall—only some species are susceptible to infection by *Agrobacterium*, and getting DNA into other plants requires the use of a gene gun, which is imprecise and damages plant tissues. Landry sees the most promise from carbon nanotubes, which can be loaded with a variety of cargoes (DNA, RNA, or proteins) and diffuse easily into plant cells. "With this technology, all we really need to do is mix two tubes together—DNA with carbon nanotubes and a plant sample—and

we have a genetically transformed plant at the end. So, I'm hoping that this would be useful in expediting the way that we do molecular biology in plants," Landry says.

Though Landry's technology is still in development, varieties of CRISPR-edited mushrooms[11] whose flesh does not turn brown when exposed to air and corn[12] that is "waxier" for optimal use in products like glue sticks have received the green light from the USDA (though, as of May 2019, they have yet to hit the market), and a growing number of companies are investing in gene-edited crops.

Cambridge, MA-based startup Inari Agriculture is using CRISPR as part of its breeding program to create seeds that can be personalized for an individual farm's specific conditions like climate and soil quality.[13] Benson Hill Biosystems, founded in St. Louis, MO in 2012, aims to put gene editing in the hands of food producers through their CropOS software system, which allows growers to predict which breeds will work best for their fields, identify potentially helpful genes from other organisms, and create customized gene-edited varieties.[14] And existing industrial agriculture leaders are getting into the CRISPR game as well. "If you imagine any trait that might be beneficial for crops—anything from drought tolerance to disease resistance—variation in that trait exists in nature already. What's really exciting about gene editing technology and CRISPR technology is not only can it recreate some of that same variation in plants, but it can also create a new variation that can then be selected for," says Scott Knight, Head of Genome Editing and Yield at Bayer Crop Science. "We imagine that gene editing is going to work side by side with all of the previous work that we've done in breeding and traditional biotechnology over the last several decades."

Not everyone is as open to CRISPR-edited crops as the USDA and the American agriculture industry, however. The EU recently declared that all CRISPR-edited plants would fall under its GMO regulatory framework, which effectively puts an indefinite moratorium on any significant gene editing research and development on the European continent.

The anti-GMO movement sees the USDA's decision not to regulate gene edited crops as a shortsighted move that favors industry at the expense of consumers, who will be at risk of exposure to potentially harmful products without their knowledge or consent. The Non-GMO Project's website states that, "All genetic engineering is inherently reductionist and relies on unproven and unreliable assumptions about the predictability of a given gene's function in isolation from its original DNA sequence." Dana Perls, the Senior Food and Agriculture Campaigner for environmental advocacy group Friends of the Earth, wrote in an opinion article for STAT News, "We need more science, assessment, answers, and regulations before we can decide whether these new biotech products should be in our stores—and on our plates.[15]

Improving biology with biology

Some scientists and companies have decided to steer clear of any genetic modification in plants, whether performed by traditional GMO techniques or CRISPR, in their quest to improve crop yields. One of those scientists is Neena Mitter, a Professor at The Queensland Alliance for Agriculture and Food Innovation in Brisbane, Australia. She first worked on developing vegetable crops that were genetically resistant to viruses and other pathogens using the technique of RNA interference (RNAi), in which segments of DNA are inserted "backwards" into the genome so that they are transcribed into molecules of RNA that bind to and "silence" a complementary target RNA sequence. "It worked beautifully well, but very soon I realized it was not going to reach anywhere because industry [in Australia] was not going to fund research on genetic modification of vegetable crops," Mitter says. "I started asking myself, 'RNAi is such a wonderful tool, is there a way I can deliver it to plants while bypassing genetic modification? Can I just spray it on a plant and make it resistant?'" It turned out that a plant cell's natural RNAi machinery can be jumpstarted by the introduction of a targeted, double-stranded version of RNA (dsRNA) that is common in viruses, without requiring genome editing. The idea of spraying dsRNA onto plants to control viruses had been proposed before, but the molecule degrades within a few days of application, which would require farmers to spray their fields almost constantly to maintain protection.

Mitter partnered with nanoengineers at the Australian Institute of Nanoengineering and Nanotechnology to develop a new technology called BioClay that packages dsRNA into nanoparticles made of a type of clay called layered double hydroxide. The nanoparticles protect the dsRNA and allow it to be released slowly onto the plant, where some of it is taken up into the plant's cells and, if a virus or other pathogen infects the cell, triggers the cell to destroy the invader's RNA. BioClay particles sprayed onto plants can stay in place for up to a month, even through heavy rain, and leave no residue. "The beauty of this approach is that it works just like any other crop protection scenario, and it's recognized as a non-GM approach," says Mitter. "We need to understand that integrated pest management is the key for the future. There is no chemical available now

(11)https://agsci.psu.edu/magazine/articles/2016/fall-winter/a-crispr-mushroom
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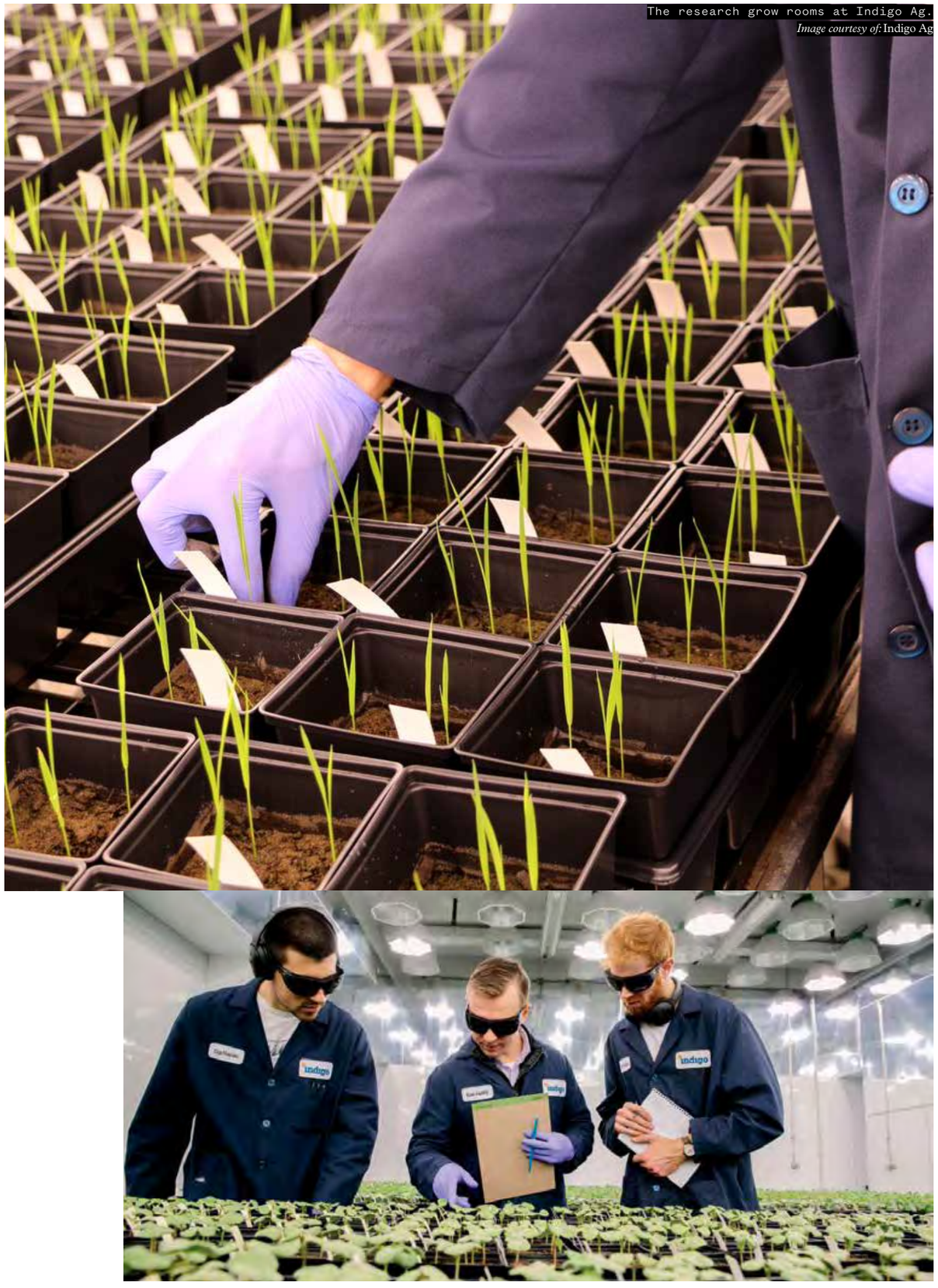

The research grow rooms at Indigo Ag.
Image courtesy of: Indigo Ag

Other scientists think that focusing on molecules, whether DNA or RNA, is an oversimplified approach to a complex problem. Just as there is growing acceptance that the "microbiome" that inhabits our guts has significant effects on our health, there is increasing interest in studying and understanding the communities of microbes that live within plants.

that can kill a virus in a plant system—current treatments target the insects that transmit those viruses. BioClay provides a unique solution that can target the virus itself."

Other scientists think that focusing on molecules, whether DNA or RNA, is an oversimplified approach to a complex biological problem. Just as there is growing acceptance that the "microbiome" that inhabits our guts has significant effects on our health, there is increasing interest in studying and understanding the communities of microbes that live within plants. "Any plant, if cut open, has microbes living on the inside of its tissues—every blade of grass in your lawn, every leaf of every tree on the Boston Common, every rainforest in the world," says Geoff von Maltzahn, co-founder and Chief Innovation Officer of Boston-based Indigo Ag. "Anything that compromises the health of the plant compromises the microbes' health, so it would be in their best interest to evolve protections against that. We thought that maybe the internal plant microbiome could be a home for solutions to every challenge that farmers face in agriculture."

Indigo Ag analyzes the microbes naturally found inside healthy plants, identifies those that confer certain advantages, and sells seeds pre-coated with microbes to farmers. As the seeds germinate, the microbes incorporate into the seedlings' tissues and provide support throughout the plants' lifetimes. "We could never have designed an intervention as powerful as what we've discovered in 'Nature's lab,' because every time we isolate microbes from a plant, we're benefitting from millions of years of Nature's R&D," says von Maltzahn. "GMO interventions are like transistors compared to the supercomputer that is a microbe that has evolved to live in and support a plant."

Other companies are also using microbes to deliver benefits to plants. Growcentia, based in Fort Collins, CO, focuses on bacteria found in the soil, and has developed a blend of four species that have been proven to "liberate" phosphorous from the soil so that plants can better absorb it and use it to grow. Bayer has teamed up with Ginkgo Bioworks to form a new company called Joyn Bio, which is combining gene editing and microbe science by identifying the genes that give microbes their plant-supporting characteristics, then boosting them. "At Joyn, we're focusing on microbes that already have these pathways present and enhancing their ability to carry out natural processes that are beneficial for agriculture," says Brynne Stanton, Joyn's Head of Metabolic Engineering. The first of those processes the company is targeting is microbes' ability to "fix" nitrogen from the soil and make it available to plants, thus reducing farmers' dependence on nitrogen fertilizers and the fossil fuels used to produce them.

Neena Mitter
Affiliate Professor,
Australian Institute for
Bioengineering and Nanotechnology

Geoffrey von Maltzahn
Co-founder & Chief
Innovation Officer, Indigo Ag

The final digital frontier

A crucial component of the "Second Green Revolution," as some are calling today's agricultural innovations, is digital tools to help farmers catalog and analyze the large number of variables they encounter every day.

One such system is Bayer's FieldView, which allows farmers to build digital maps of their fields to track which crops are planted where and monitor their performance, and includes an Alexa-like device that plugs into their harvesting equipment and links that data with information from their machines. "It's often said that agriculture is the last industry to be digitized, and we're living that right now," says Knight. "Growers want this technology. They're very tech-savvy, they're out there now in their fields with their iPads gathering information in real-time, and they strive to make those data-driven decisions."

Digital tools are the glue that will help hold future agriculture together, linking soil and seed to algorithms and artificial intelligence, and many agricultural companies are diversifying to provide that value to farmers. "Growers can make up to millions of individual decisions every year, and many of them are based on intuition and experience without a lot of sophisticated data to guide those," says Indigo Ag's von Maltzahn.

If the Green Revolution was built on the four pillars of hybrid seeds, irrigation, mechanization, and chemicals, the current revolution in agriculture is being driven by the triumvirate of gene editing, biological-based interventions, and digital technology.

Brynne Stanton
Head of Metabolic Engineering,
Joyn Bio

Jonathan Giebel
Program Lead: Bayer LifeHub
Boston, Bayer

While those fields may be new to agriculture, they're commonplace in established tech clusters like those found in Cambridge, MA. Bayer set up shop in the area's biotech-heavy Kendall Square when it opened its "LifeHub Boston" space in 2017, which serves as a way to monitor the pulse of the local tech community and encourage the development of novel solutions to the looming food scarcity problem. "What many people don't realize is that agriculture innovations are just as difficult and expensive to bring to market [as pharmaceutical innovations]," says Jon Giebel, Program Lead of LifeHub Boston. "We're here [in Cambridge] to help these entrepreneurs and university groups who are doing great science for human health applications, and show them opportunities to translate those into the plant health, food production, and crop yield spaces."

The excitement around agriculture technology is palpable, especially because it has the potential for such broad-reaching impact. "In many ways, agriculture is the most important life science in the world," says von Maltzahn. Just as successfully growing a plant requires the perfect combination of soil, sun, water, nutrients, and time, finding new ways to feed the world is an all-hands-on-deck effort between corporations, tech companies, scientists, and farmers. As Bayer's Scott Knight notes, "Being able to provide tailored solutions that really put the right seeds at the right time in the ground, perhaps with the right microbe, is going to be critical to provide a sustainable and safe food supply for the future."+

Digital tools are the glue that will help hold future agriculture together, linking soil and seed to algorithms and artificial intelligence, and many agricultural companies are diversifying to provide that value to farmers.

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Waste not

Up to 40 percent of food is wasted on its way from the farm to your mouth. These companies are trying to change that.

By *Michael Blanding* for *The Engine*
Illustrations by *Andrés Rodríguez*
Opening image by *Aryeh Kornfeld*

Cambridge Crops CEO Adam Behrens unzips a blue cloth and pulls it away from a rack of shelves. Sitting neatly in rows are a dozen or so avocados, with small Post-It Notes indicating the date that they were placed there. The gnarled fruits look almost identical, aside from a slight sheen on some of their peels—but that nearly imperceptible difference has a huge impact on how long they can last before spoiling. "We are seeing a two to three times increase in shelf life," says Behrens, who wears glasses and a grey MIT sweatshirt.

The company's secret lies in a cardbox that Behrens now pulls down from the shelf. Inside are what looks like hundreds of hollow, Styrofoam packing peanuts. In actuality, they are silkworm cocoons—the same material used by the garment industry to make a silk shirt or dress. He and his colleagues at the company Cambridge Crops take these cocoons, boil them, and then hit them with salt to free silk fibroin, a naturally occurring, non-toxic, and biocompatible protein. They then dissolve it in water, so it can be spread over the surface of a food. Once dry, the solution reforms into something very much resembling the original cocoon that protected the silkworm during its metamorphosis.

"These cocoons evolved to protect a super delicate biological transformation with specific gas diffusion and anti-microbial properties," Behrens says. "We can lend those properties to a food item in an unperceivable film." Avocados are just the beginning for Cambridge Crops, which is experimenting with applying its protective coating to food items including apples, fish, poultry, and beef. The company is part of a technological revolution to extend the life of our foods on their journey through the food supply chain, including production, packaging, distribution, consumption, and disposal.

Depending on the estimate, between 30 and 40 percent of the food in the U.S. never makes it from the field to our stomachs—that's 63 million tons annually, or more than a pound of food per person each day. It rots in the fields, spoils in trucks, wilts on supermarket shelves, or gets scraped from our plates into the trash. As much as all that decay is a tragedy, it is also an opportunity, says Chris Cochran, director of ReFED, a nonprofit dedicated to reducing food waste. "I come at it from the angle of 'How do we feed 10 billion people by 2050, when we don't have the land or additional natural resources to put to food production?'" he says. "One of the most natural places to start is to look at waste in the food system."

Cutting down waste could have a dramatic environmental impact, as well. The majority of natural resources in the U.S. are used for agriculture and food production, Cochran continues, and waste alone accounts for some 20 percent of water usage, and 8 percent of global greenhouse gas emissions. "It's production of fertilizer used on farms, it's fuel for the farm implements, it's fuel for transporting food thousands of miles by airplane or truck—often in refrigerated conditions—and it's methane released from unconsumed food in landfills," Cochran says.

In fact, tackling food waste is one of those rare enterprises that is a true win-win-win, increasing the supply of food, improving the environment, and potentially saving companies money by increasing efficiency in the system. Perhaps that is why two-thirds of food companies have endorsed the United Nation's ambitious goal of cutting food waste in half by 2030. "The food industry is a low-margin business, and it is becoming increasingly competitive," Cochran says. Entry of companies like Amazon and Wal-Mart into the grocery market, along with an explosion of online delivery options has created incredible price competition in the industry. While food companies have once seen waste as a cost of doing business, now many are aggressively pushing to discover previously unexamined ways to reduce spoilage.

Growing Smarter

That supply chain starts with production at the farms and slaughterhouses of all refrigerated food containers in the world. Two years ago, it launched Maersk Growth, a venture arm that has so far invested in 10 companies, half of which are tackling the problem of food waste. Last year, it launched FoodTrack, a month-long incubator program at its company headquarters in Copenhagen to provide support for early-stage companies, ending in a demo day in which they can pitch for funding. Maersk Growth venture partner Peter Jorgensen sees technology as key to overcoming waste in food distribution—which can total a $1 trillion loss worldwide each year. "There is a lack of visibility and data in the industry that runs much more analog than digital," he says. "We need to drive a substantial change in digitization and through that create more visibility and more effective supply chains."

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ReFED tallied some $125 million invested in the first 10 months of last year. It is now tracking 500 startups in the space, half of which have emerged in the past five years. Unlike some other startup industries, their business model is often clear—capturing some of the value of waste for companies growing and transporting food, while pocketing a percentage of it themselves. "Step one is to charge the customer for the product or service you are providing," says Niko Hrdy, president of Valley Oak Investments, an investor in food waste companies such as Spoiler Alert and Hazel Technologies. "You say, if you use this product, you will make an extra 20 dollars, and you only have to pay me 5."

Some big companies are getting involved in the space directly. Shipping giant Maersk transports 30 percent that produce the vegetables and proteins that eventually make it into our dinner. Farms have long been experimenting with technologies to improve efficiency and help them deal with all of the unpredictability of drought, blights, pests, and labor shortages. For years, farmers have had to rely on manual inspection to determine how to tend and pick their crops; now a host of new surveillance technologies are doing the job for them. Companies including Boston-based GreenSight and North Carolina's PrecisionHawk are using autonomous drones to give farmers bird's-eye view of their fields. Other companies are using satellites to take high-resolution images of their fields using techniques like hyperspectral imaging to determine soil and crop health. There are also more

Adam Behrens
Co-founder & CEO,
Cambridge Crops

Chris Cochran
Executive Director,
ReFED

Niko Hrdy
President,
Valley Oak Investments

Peter Jorgensen
Partner,
Maersk Growth

Orin Hoffman
Venture Partner,
The Engine

Brandon Alexander
CEO, Iron Ox

options for these companies to get this high-fidelity data to the ground, including Boston-based Analytical Space. "Now a farmer can really do targeted pesticide use or optimize water use, which can have a huge impact on crop yield," says Orin Hoffman, a venture partner at The Engine and former executive at iRobot and Endeavor Robotics. "As that data becomes collected and combined with improved weather models, it can help to track blights and droughts nationwide."

While at iRobot 15 years ago, Hoffman worked with John Deere to implement robotics into harvesting as well. "At that time the Holy Grail was to have the treads of a tractor fall within one-inch of where the treads had gone before," he says—a goal that could lead to massive efficiencies across millions of acres of cropland. Now industrial farmers are using a wide array of robotics and GPS systems to better harvest broad-acre crops such as wheat and other grains; the next challenge is to apply the same technology to better harvest more delicate crops such as citrus or strawberries. Strawberry company Driscoll, for example, has been working with Spanish company Agrorobot to develop a robot with 24 mechanical arms that can endure the rugged conditions of the field in order to effectively pick fruit. "Robotization of farms is really hitting an inflection point right now," Hoffman says. "Advances in industrial manipulation as well as abilities to operate equipment outside has collided to create incredible new capabilities in farming equipment."

San Francisco–based company Iron Ox has pursued a different approach: instead of bringing robots outside, it is bringing the plants indoors. CEO Brandon Alexander grew up on a farm in Texas that raised broad-acre crops like alfalfa and cotton, seeing new technologies aid in harvesting those crops firsthand. "That's great for crops that are going to be converted into another product," he says. "It's okay to damage wheat because it's going to be converted into flour." With more delicate items, such as strawberries, tomatoes, and lettuce, however, margin for error is much smaller. "Each crop you grow, every varietal of lettuce or strawberry is slightly unique so you can't apply mass industrial automation techniques to it."

Alexander worked at Google[x] as an engineer on its drone program, but in 2015, he left to found Iron Ox, focused on automating farming for those more delicate crops. Last October, the company opened its first fully autonomous farm, which uses indoor hydroponics to ensure uniformity of growth and increase yields, and robot pickers to harvest them. "We can grow year-round in a climate-controlled environment, and don't have to worry about rain or nutrients." By controlling the nutrient mix the plants get through hydroponics, the company can dramatically increase yields—growing 26,000 crops in 8,000 square feet—30 times the yield of a traditional farm.

Harvesting is done by two robots, a larger mobile one named Angus that moves pallets of plants to the processing area, and then a precise, seven-jointed robot arm that picks the crops. "You can almost think of it like a surgeon," says Alexander. The arm comes equipped with two cameras similar to human eyes, so it can see in 3-D and calculate on the fly the right trajectory to come at each plant with the right delicacy.

Alexander envisions these microfarms located across the country, serving local food markets. The average produce travels 2,000 miles from farm to consumer, and could be a week old by the time it gets to supermarket shelves. Iron Ox's goal is to cut that distance down to 20 miles, so restaurants and supermarkets can literally stock produce in the afternoon that was on the plant that morning. "A lot of varietals that are selected today are selected based on their shelf life rather than taste or nutrients," says Alexander. "It's not like anyone has ever said, 'I love iceberg lettuce.'" Right now, the company is working on bringing down costs, switching from LED growing lights to greenhouses to utilize sunlight instead of electricity and increase environmental sustainability as well.

Other companies are using similar technology to hydroponic technology

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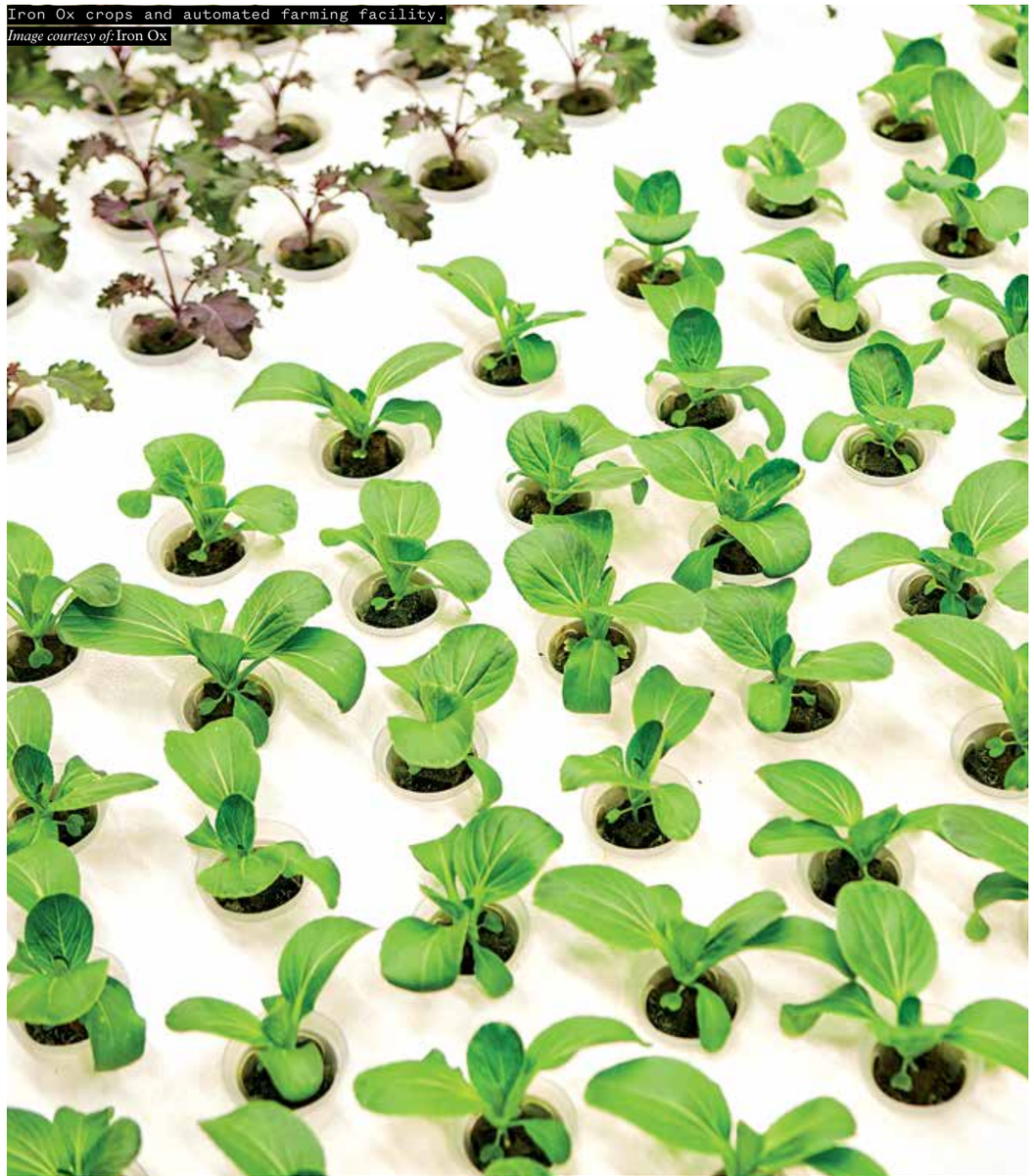
Iron Ox crops and automated farming facility.
Image courtesy of: Iron Ox



to grow food more efficiently. San Francisco's Plenty grows kale and other greens with vertical farming technology in a 200,000 square-foot warehouse, using strings of LED lights facing walls of plants growing horizontally, a technique the company says uses less energy. The company, which includes veterans of Twitter and Tesla is backed by the likes of Amazon's Jeff Bezos, and has begun selling its produce in the Bay Area. Boston-based Freight Farms, meanwhile, is pursuing a less-is-more strategy, pioneering self-contained farms inside 40-foot shipping containers. In the past decade, the company has sold more than 250 container farms to corporations, colleges, and other organizations. Its latest next-generation farm sells for $104,000, and features moveable panels that can grow everything from herbs to tomatoes to some root vegetables. Not only do the container farms grow crops more efficiently, but they also reduce spoilage by cutting the distribution distance to zero.

While it's important for fresh produce to be used right away, other crops such as wheat and other grains are often stored for months on end until they are needed. That storage comes fraught with risk, however—damp, insects, and fire—that can wipe out whole silos of grain before it can come to market. Serial entrepreneur Naeem Zafar was looking for new applications for the "internet of things," machines talking with other machines, when he stumbled on the problem of post-harvest grain storage. "It's a very large but somewhat obscure market," Zafar says. "But it turns out that some $14 billion of waste happens every year."

The solutions farmers and distribution companies have come up with to prevent that waste are often inadequate, hanging cables from the ceiling to detect changes in temperature or moisture. "The rest is prayer and intuition, and someone opening the bin and sniffing it and saying something is wrong," Zafar says. Starting in 2014, he began raising funds for a new startup, TeleSense, to produce a grapefruit-sized plastic ball equipped with sensors that could be thrown directly into grain and wake up every few hours to transmit data about conditions inside the pile. Zafar worked with this co-founder, chief engineer Nick Garner, to develop a product that could transmit through grain, and have long enough battery life to be useful.

The sensors, which the company rents for $30-40 a month per unit, could be placed every few meters with a grain elevator to provide a comprehensive view of a grain elevator operation. "You should be able to start monitoring your whole facility for anywhere between $2,000 to $5,000" a month, Zafar says. Because the balls are all connected, however, they allow a farmer or grain elevator company to detect patterns over time, using machine learning to monitor differences by season, or even by hour to make changes in their facility to improve storage. "You might see you get your hottest sun between 10 and 11am, and storage unit #2 doesn't have as large a shadow as unit #3," says Zafar, "and you are able to take action."

So far, the company has introduced the technology in the Midwest and California, as well as Australia, where one large company used it to save $3 million worth of canola by preventing hotspots within the grain. "They would not have noticed it if it weren't for continuous monitoring," Zafar says. "They used to send someone to check every few hours. This saves labor costs and improves inventory." Last year, the company closed a Series-A round of funding, raising $6.5 million led by Maersk Growth. It hopes to expand into Eastern Europe and Latin America, as well as develop new products that can monitor grain within shipping containers around the world.

From Field to Fork

In addition to food that is unintentionally wasted during harvesting and storage, some food is wasted on purpose during processing. When Kaitlin Montegale moved to Los Angeles for a program in environmental studies at the University of Southern California (USC), she was struck by the presence of so many juice bars, which seemed to be on every corner. Watching a friend juice a carrot one day, she saw just how much little juice came from the vegetable compared to the pulp still in the juicer. "She had all this waste left behind," Montegale says. "At the same time I was keenly aware there are so many people around the world who don't have access to fresh foods."

The stages of the Cambridge Crops coating: raw silk, dehydrated silk protein, dissolved silk protein, coated strawberry.
Image courtesy of: Nathaniel Brewster.

"Typically, a membrane is either a good barrier for oxygen, or a good barrier for water. Given the structure of polymers, there is a mutual exclusivity between the two," says Marelli, now an Associate Professor of Civil and Environmental Engineering at MIT.

Naeem Zafar
Co-founder & CEO,
TeleSense

Kaitlin Mogentale
Founder,
Pulp Pantry

Through a business incubator at USC, she began collecting pulp from the many juiceries on campus, and experimenting with recipes to turn it into an appealing snack. "I became passionate about using pulp as a means to achieve that and get more fruits and vegetables into people's diet," says Montegale, who founded a company Pulp Pantry in 2015. She bootstrapped the startup with grants from entrepreneurship programs such as Burt's Bees Natural Launch Pad, which focuses on women entrepreneurs. Now, four years later, she is selling a line of plant-based "granola bites" in flavors such as cinnamon toast and vanilla sea salt. "For me, it was about taking this fruit and vegetable byproduct that was super-unappetizing, and disguising it in a way that would be both highly marketable, and delicious."

Montegale downplays the food waste aspect in promoting the product, focusing on the taste and health benefits. Once consumers are hooked, however, the sustainability piece is a bonus. "The story of food waste is not the number one issue on people's minds, but it's definitely something that keeps people engaged," she says. "A lot of people are excited about sustainability and that resonates with them." While Pulp Panty started with small juicers and an LA-based farmer's co-op, "that's not a super-scalable model," Montegale says. The company is now working with commercial juicers, which produce millions of pounds of pulp every year, and also experimenting with new products such as a veggie chip.

However food is harvested, it must eventually make its way to restaurants or consumer's kitchens, often traveling in refrigerated containers in a race against spoilage. Various companies have been taking on the challenge of improving the stability of food on that journey. San Francisco–based Ripe, for example, has applied blockchain technology to track individual packages and identify bottlenecks and delays along the way that can cause spoilage. "A consumer-facing business can purchase food and have the assurance that it has been maintained in good conditions and winter tomatoes didn't get stopped in the heat for 12 hours," Cochran says.

One of Valley Oak's investments, Chicago's Hazel Technologies is using a technology developed at Northwestern to promote small satchels packaged with fruit that emits a chemical, 1-Methylcyclopropene, that slows ripening and maintains freshness. San Francisco-based Purfresh uses ozone technology to replace the atmosphere in shipping containers to delay ripening of produce, and reduce spoilage from harmful bacteria. Global food company Wheatsheaf recently acquired a 90 percent stake in the company. Santa Barbara–based Apeel Sciences recently raised $70 million from the likes of Viking Global Investors for a plant-based protective coating that can be sprayed onto fresh produce such as bananas, oranges, and strawberries to extend their shelf-life and cut down on the need for refrigeration.

Cambridge Crops has taken a different route with its silk-based technology, applying it not only to fruits and vegetables, but also to meat, fish, and poultry. CEO Adam Berhens got his start at The Langer Lab at MIT, where he was researching ways to keep vaccines and vitamins stable for long times in non-refrigerated environments. From there, he pivoted to looking at the problem of food more generally, partnering with Sezin Yigit, who had done doctoral work at Tufts University, which has pioneered new uses for silk as a wonder material for everything from artificial organs to nano-optics. There, assistant professor Bendetto Marelli was experimenting with a new water-based silk solution that could be applied to foods without affecting their taste, color, or cooking properties.

"Typically, a membrane is either a good barrier for oxygen, or a good barrier for water. Given the structure of polymers, there is a mutual exclusivity between the two," says Marelli, now an Associate Professor of Civil and Environmental Engineering at MIT. "Silk somehow has both qualities." The barrier prevents both dehydration, which can cause food to

Pulp Pantry's granola bites.
Image courtesy of: Pulp Pantry

Ricky Ashenfelter
CEO, Spoiler Alert

Benedetto Marelli
Associate Professor of Civil and Environmental Engineering, MIT

"Because of the way the economics works out in the meat industry, if you can increase the shelf life and reduce waste, then it does filter up to produce fewer cows, as well as reducing the overall emissions associated with the industry, without reducing economic activity," says Ariel Horowitz.

dry out and lose shape, and oxidation, which can change color and flavor. In addition, silk provides a natural barrier to microbes, which can cause food to spoil. Marelli first started experimenting with silk for biomedical applications as an undergrad at the Polytechnic Institute of Milan. While at Tufts, he coated some strawberries in silk as part of a lab cooking competition, and serendipitously discovered its unique properties. "I left them on the bench--when I came back four or five days later, the ones there were not coated spoiled, while the other ones did not."

Cambridge Crops received an investment from The Engine in January 2019, and received funding from the Massachusetts Clean Energy Center (MassCEC), a quasi-government agency focused on reducing climate emissions, the following month. It is currently based at Greentown Labs, a clean-tech incubator in Somerville, Massachusetts with 100,000 square feet of co-working space for environmentally minded firms. "We have a unique need for square footage, but also biological and chemistry equipment," says Behrens, surrounded by high-tech chemistry instruments to measure attributes such as crystallinity and gas diffusion. "A traditional lab wouldn't allow us to have a bunch of food lying around."

The company is now midway through its safety review with the Food and Drug Administration (FDA); once it receives a stamp of approval, it will begin to commercialize its technology, Behrens hopes, by the end of this year or early next. Cambridge Crops is focusing on higher-value food products such as meat, fish and pre-cut produce, where an extra few cents would become economically justified in increased sales. "Because of the way the economics works out in the meat industry, if you can increase the shelf life and reduce waste, then it does filter up to produce fewer cows, as well as reducing the overall emissions associated with the industry, without reducing economic activity," says Ariel Horowitz, Director of Technology Development at MassCEC.

As Behrens envisions it, the silk-based solution would be incorporated directly into the workflow at the producer, used in place of water to wash produce before shipping, or applied to large cuts of meat before heading to processors that will cut them down into retail cuts. The incentive on the other hand, will be with retailers and restaurants, who will reap the benefits of having a longer shelf life, allowing them to waste less food and sell more to customers. "We need big retail to ultimately pressure their supply chain to spec out foods that have a longer shelf life," he says. That could be done by specifying products such as Cambridge Crops, or more likely, by setting minimum standards for producers and leaving it to them how they will achieve it. "They could just say, we want a salad mix that lasts 14 days instead of 7."

The best technology won't prevent spoilage of food; it will only limit it. Once food products are on the shelves of distribution companies and supermarkets they are in a race against time to prevent waste. And no matter how efficient the system is, companies need to stock excess inventory to prepare for the unexpected—a snowstorm, a sports championship—that could lead to a run on their shelves. Helping deal with those realities is Spoiler Alert, a Boston-based firm that has created enterprise software to help distributors better manage food that otherwise may lose its battle with the clock. "There is a disconnect in our food system between the major hubs of our system that allows a lot of very good food to go to waste," says Spoiler Alert's CEO Ricky Ashenfelter, sitting in a plant-filled office in Boston's Back Bay neighborhood. "One of the enablers of that is a lack of information sharing."

The company grew out of MIT's Sloan School of Business, where Ashenfelter met cofounder Emily Malina. "Night and weekends working on the project ended up giving me an MBA in food waste," says Ashenfelter, who had a background in climate change and sustainability. Wanting to do something to focus on the huge amounts of waste in the food supply chain, the pair focused in on large distribution centers as the crucial hub between farmers and producers on the one hand, and supermarkets and restaurants on the other. With all of the other logistics they are managing on a day-to-day basis, saving food from spoiling is never their highest priority. "It's never anyone's one, two, or three job, but it is often their number one or two painpoint, and the thing that takes up their time," Ashenfelter says.

Hooking into those companies' inventory systems, Spoiler Alert's software takes that hassle of their hands by helping to identify "distressed inventory"—products at risk of going bad from expiration, spoilage, or damage—and figuring out how to repurpose that food before it goes bad. Oftentimes that means either selling to discount retailers such as Big Lot, or donating to hunger relief organizations for a tax benefit. The company launched in 2015, and has since raised $5 million from funders including Valley Oak and Maersk Growth, which is helping the company expand beyond distribution centers to other points in the transportation and supply chain.

For Ashenfelter, the payoff from tackling food waste is its broader effect on the environment, including reduction of greenhouse gases that cause climate change from producing or transporting food that isn't used. If all of the emissions from food waste were tallied, Ashenfelter says, it would place third behind the US and China in the largest contributor to climate change. Unlike some environmental issues such as water scarcity, however, it's an issue that every consumer can feel each time they scrape uneaten food into the trash, or throw away spoiled meat in their fridge. "With other issues you struggle to that kind of recognition," Ashenfelter says. "Food is so tangible, it makes it easier to talk with consumers and see the effect of the issue on their lives." All of these technologies and companies are working towards the same purpose, whether they are coming at it from the angle of saving the environment, or just saving money. After all, as ReFED's Cochran says, "It will never make sense to turn food into compost." +

Annual food waste in the United States

The United States spends over
$218 billion
growing, processing, transporting, and disposing of food that is never eaten.
That is 1.3% of GDP.

52.4 million
tons of food is sent to the landfill.

10.1 million
tons of food remains unharvested.

63 million
tons are wasted annually

Source: ReFed, A Roadmap to Reduce U.S. Food Waste by 20 Percent, 2016

THE ENGINE PROVOCATIONS+

Bringing Transformative Food & Ag Tech to Market

On May 3rd, 2019, The Engine hosted nearly 50 food & ag-tech leaders from across the country—scientists, chefs, researchers, farmers, entrepreneurs, restaurateurs, and investors—to workshop common challenges and help lay the groundwork to bring more transformative companies and ideas to market.

What is a Provocation?

Provocations are small, collaborative, invite-only events that help inspire segments of the Tough Tech ecosystem to connect and solve real industry challenges.

Participants

How Might We?

Transparency, Traceability, Metrics & Data

- How might we create a more transparent industry given an incredibly fragmented and complex supply chain?
- How might we foster the adoption of a common set of metrics across the supply chain?
- How might we provide access to meaningful data without putting individual growers at a competitive disadvantage?
- How might we establish a seamless flow of data across the supply chain, from grower to consumer?
- How might we store the data we generate across the supply chain? And how do we permission its use?

Marketing & Storytelling

Growers

- How might we make the stories of growers more compelling and accessible?

Education

- How might we more effectively teach our children where their food comes from?
- How might we showcase food & ag as an exciting sector for innovators in science and businesses?
- How might we win the battle for GMO?
- How might we motivate the next generation to work in food and ag?

Investment & Capital

- How might we educate investors about the opportunity in the food & ag industry?
- How might we accelerate pilots and demos in accessing new technologies and approaches?
- How might we build awareness and encourage greater investment?

Labor

- How might we ensure that our workplaces are as safe as possible?
- How might we reconcile the increasing automation of our industry with the needs of our current workforce?

Regulation & Policy

- How might we, as the scientific and industrial community, play a more proactive role in regulatory discussions?
- How might we better understand the nuances of how public perception influences regulation?
- How might we accelerate advances in the labs being tested in the fields?

Packaging

- How might we encourage more sustainable packaging and overall waste reduction?
- How might we design smarter packaging?
- How might we sustainably extend shelf life?

Growers

- How might we build incentives to help growers test and adopt new technologies?
- How might we give growers more insight into how they can optimize their resources like water, soil, and antibiotics?

Consumers

- How might we design a sustainability score to help consumers make informed choices?
- How might we make it easier for consumers to know which foods are best for them?

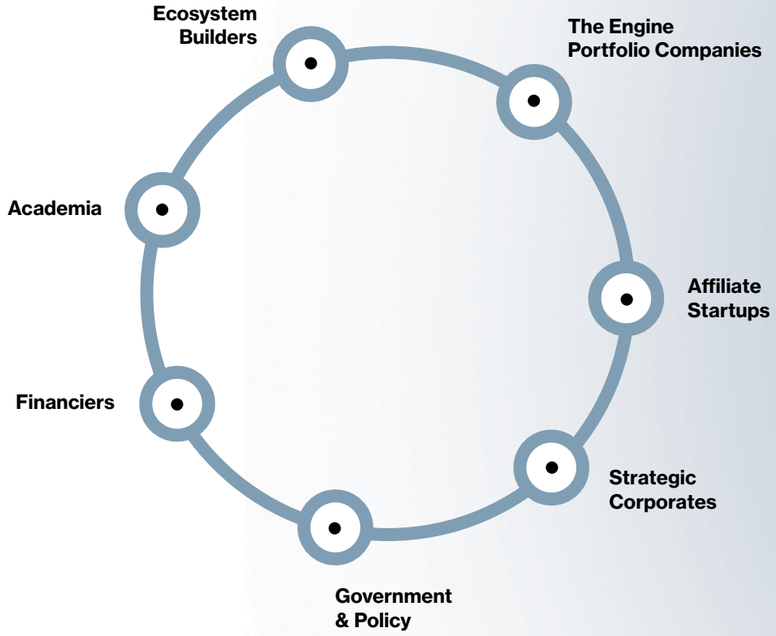
Technology

- How might we make scientific and technical founders aware of the possibilities within the food & ag industry?
- How might we accelerate new technologies out of the lab and into the fields?




THE ENGINE NETWORK

The Engine Network facilitates the creation of long-term mutually beneficial relationships between founders, startups, corporates, government, and strategic partners, among others.



The Engine Network Members

Portfolio Companies

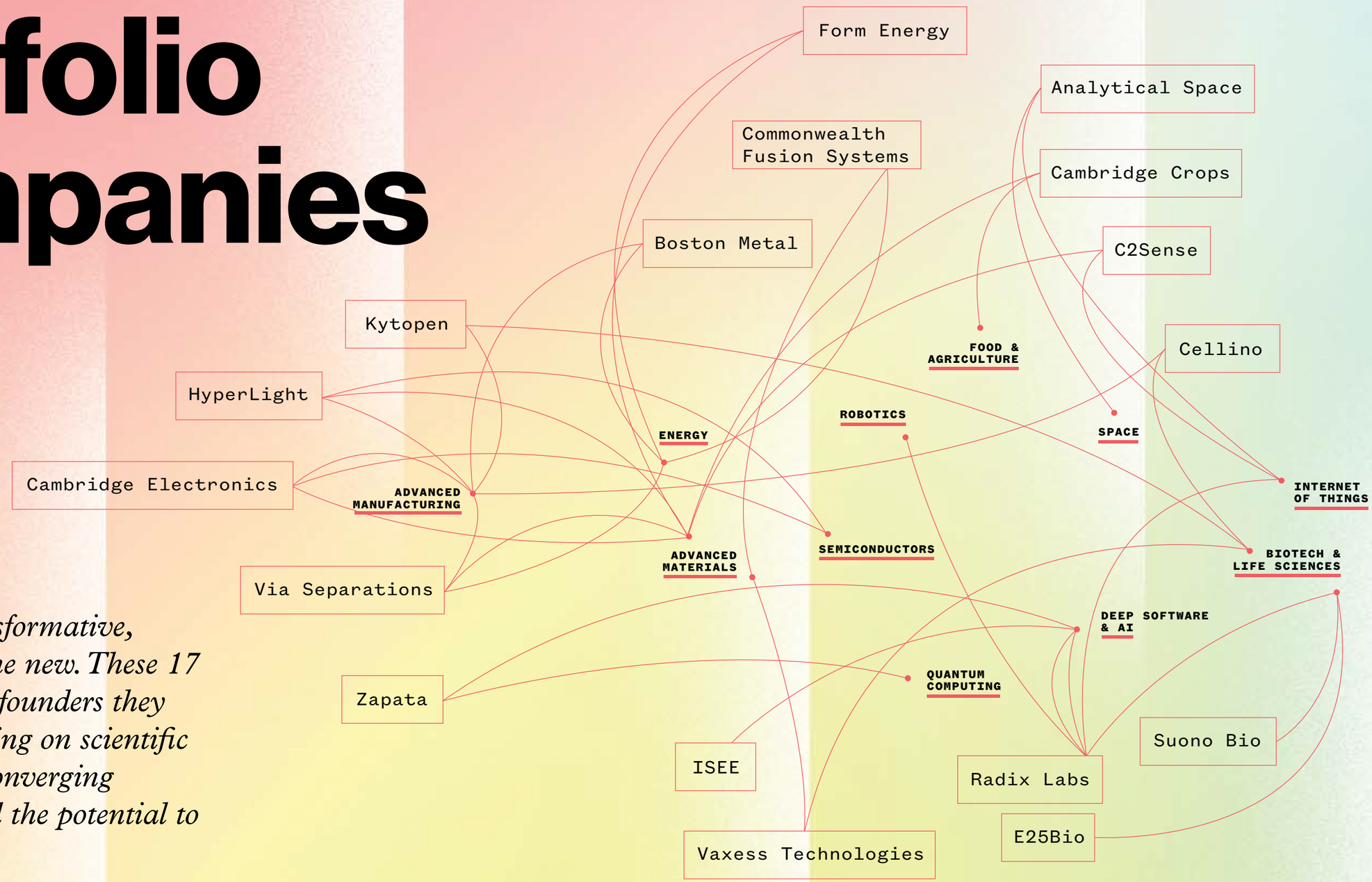
Analytical Space
Boston Metal
C2Sense
Cambridge Crops
Cambridge Electronics
Cellino
CFS
E25Bio
Form Energy
HyperLight
ISEE
Kytopen
Radix Labs
Suono Bio
Vaxess Technologies
Via Separations
Zapata Computing

Affiliate Startups

Accion Systems
Ambri
Asimov
DOTS
DropWise
FemtoDx
Formlabs
Fortify
Gelsight
Hyalex
Inkbit
Kebotix
Landsdowne Labs
LECT
Lightmatter
Metalenz
NBD Nano
Portal Instruments
RISE Robotics
Vesper

EVONIK POWER TO CREATE
HYUNDAI CRADLE

The Portfolio Companies



We invest in the transformative, the audacious, and the new. These 17 companies—and the founders they represent— are working on scientific breakthroughs and converging technologies that hold the potential to redefine the future.

Boston Metal

Founders	**|1|** Rich Bradshaw, **|2|** Tadeu Carneiro, **|3|** Adam Rauwerdink, Donald Sadoway, Antoine Allanore, Bob Hyers, Jim Yurko
Background	MIT Department of Materials Science and Engineering
Industry	Advanced Manufacturing, Energy

Steel is a ubiquitous backbone of modern civilization. But such ubiquity comes at a cost. Steel production accounts for a staggering 7% (two billion tons) of global CO_2 emissions each year, as well as significant amounts of contaminated wastewater and other hazardous solid wastes. It is a dirty coal-dependent process that has changed little over the centuries.

Until now.

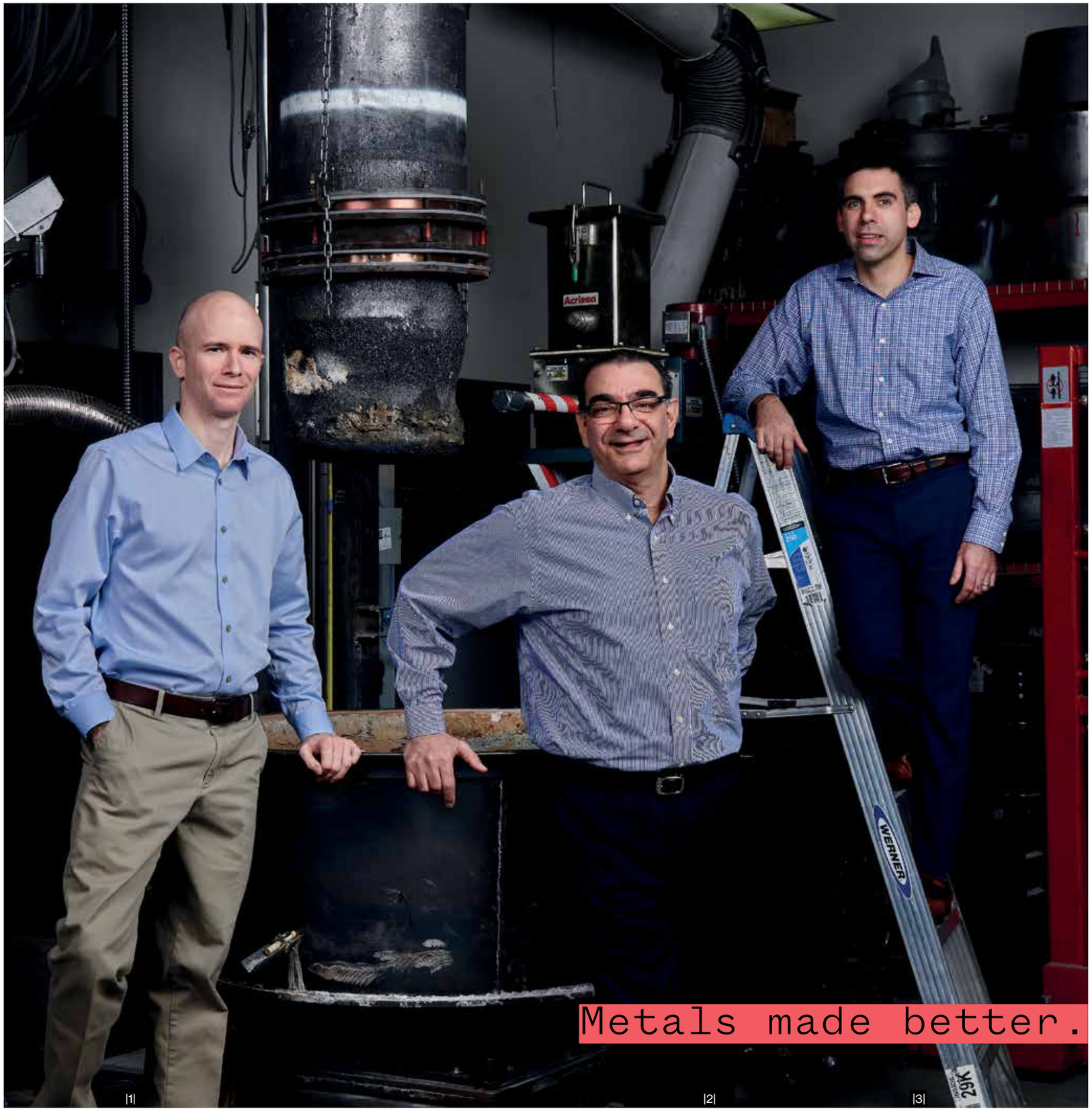
Boston Metal has invented a coal-free, emissions free, modular method of industrial steel production using electricity. It's called molten oxide electrolysis (MOE) and combines transformative materials engineering and novel systems engineering with elements from industrial aluminum production, traditional blast furnaces, and arc furnaces to produce steel more efficiently, at lower costs than traditional methods, and with zero greenhouse gas emissions.

The startup's core technology was invented at MIT in Donald Sadoway's lab with support from NASA and the American Iron and Steel Institute. Whether it is the production of reactive metals like titanium and beryllium, ferroalloys like ferrochromium and ferromanganese, or rare earth metals, the startup's platform can deliver the same clean and efficient results.

Instead of the typical five billion dollar investment needed for a new industrial blast furnace, the startup's modular and scalable approach, inspired by aluminum manufacturing, gives steel manufacturers the ability to add production capacity when appropriate. Electricity, the heart of the MOE process, is also less expensive than the relative amount of coke used in traditional blast furnaces.

The economic model proposed by Boston Metal aligns with the industry's worldwide development strategies. Humanity's appetite for steel is only increasing—and having the ability to build reliable, affordable, and clean plants close to city centers allows the industry to satisfy demand without the massive initial investment and significant ancillary costs like transportation and remediation.

Rarely is a centuries-old industrial process turned on its head. What Boston Metal has developed is a greater leap in steelmaking and metals production than the Bessemer process or the advent of basic oxygen steelmaking. It reimagines the status-quo as something that can help humanity, quite literally, reach new heights, without worrying about the air up there when it does.



|1| |2| |3|

Cambridge Crops

Founders	**|1|** Adam Behrens, Sezin Yigit, Benedetto Marelli, Livio Valenti, Fiorenzo Omenetto
Background	MIT Laboratory for Advanced Biopolymers, Tufts University SilkLab
Industry	Food & Agriculture, Advanced Materials

Once picked, harvested, or butchered, our food is on borrowed time. Add in a labyrinthine supply chain, and by the time that our avocado or steak, apple or chicken breast, reaches its final destination, it has only a few hours to a few days before the natural processes of decomposition take hold.

Because of this, the world wastes one third of the food it produces each year. In the U.S. alone, approximately $42 billion worth of fruit and vegetables are thrown out over that same period. Food waste is a problem for both the industry and public health.

Cambridge Crops is pioneering a natural, ultra-thin water-based coating that is applied to food to slow the exchange of gases that cause decay. About the thickness of two red blood cells or just a fraction of the width of a human hair, their coating is tasteless and invisible, giving food a drastically longer shelf life, without altering it in any way.

The coating also enables less or alternative packaging, as it extends shelf life independent of plastic wraps, a fact that is not lost on food producers, retailers, and environmentally conscious consumers.

When one looks at a days-old uncoated piece of raw beef or bunch of uncoated spinach versus those foods coated by the startup, the differences are striking. The uncoated meat is rancid and moldy, the spinach is brown, shriveled, an inedible. The coated foods look fresh and untouched.

What appears to be magic is thanks to the power of silk. Not silk threads like those used in the textile industry, but a water-based solution made with silk molecules. The startup's core technology renders silk invisible, but retains its key molecular properties. Being a solution, the proprietary coating can be applied quickly and easily to any shape, size, or texture by dunking or spraying.

Cambridge Crops can coat 70-80% of foods with its primary formula. Such universality bodes well for large-scale adoption. It also means that the startup can keep its costs down and compete in an industry with historically low margins. Yet even with such comprehensive effectiveness, there is room to elevate the technology.

The team at Cambridge Crops is building a true platform technology. While preserving perishable foods is the startup's immediate challenge, variants of its core tech can help stabilize active ingredients in new ways, leading to functional foods yet to be imagined.

Vaxess Technologies

Founders	**|1|** Livio Valenti, **|2|** Michael Schrader, **|3|** Kathryn Kosuda, Patrick Ho, David Kaplan, Fiorenzo Omenetto
Background	Harvard Business School, Tufts University SilkLab
Industry	Biotech & Life Sciences, Advanced Materials

The material of healing is delicate. Medicines, vaccines, blood—much of it must be stored with care and administered with precision. The need for such stability and control increases costs and decreases convenience—neither of which benefit those in need. For Vaxess Technologies, the solution to these challenges is not a synthetic preservative or a complex drug-delivery device. It's natural, water soluble, and inexpensive—silk.

The biotech and life sciences startup uses technology born out of the SilkLab at Tufts University in its novel approaches to stabilization and delivery of delicate pharmaceutical material.

Vaxess is developing a patch, roughly the size of a postage stamp, containing rows of silk microneedles that can be loaded with an array of medicines and vaccines. After a brief application, the patch is removed, leaving behind the tips of the medicine-filled microneedles painlessly within the patient. At once delicate and resilient, the microneedles dissolve at a precise rate, releasing medicine at its most effective dose and for the most effective length of time—five minutes of wear time enables two weeks of medicine delivery.

The ability for the Vaxess patch, named MIMIX, to reliably deliver controlled amounts of treatment over a precise amount of time, is not only more convenient for the patient, it is often more efficacious. In the case of immunotherapies and vaccines, the sustained delivery provided by MIMIX allows the patient's body to react in a manner similar to if its immune system was reacting to a natural infection—a slow, strong, and enduring ramp-up of immune response.

Vaxess is also pioneering a blood stabilization technology for diagnostic testing. Using the natural properties of silk fibroin to "cocoon" biological matter, the startup looks to enable patients to more readily get treatment by enabling collection and shipping of delicate blood samples.

As a biotech and life sciences company with novel core technology, Vaxess is in the unique position to do good while doing well. With more effective, more stable treatments, suddenly a world of healthcare is open to those for whom it was previously inaccessible.

Analytical Space

Founders
Dan Nevius, Justin Oliveira

Background
NASA, Planetary Resources, White House, Harvard Business School

Industry
Space & Internet of Things

Analytical Space (ASI) is building a network of in-orbit communication relay satellites that use laser communication to offer expanded connectivity for data transfer, without any change to existing hardware. This results in faster data downloading, more access to download windows, lower latency, and improved cost structures, while being compatible with heritage satellites and new satellites alike.

Significance
Analytical Space will liberate and deliver terabytes of untapped data gathered by hundreds of satellites, giving humanity a more informed and dynamic picture of everything from industrial agriculture to weather.

C2Sense

Founders & Leadership
Timothy Swager, Eric Keller, George Linscott, Jan Schnorr

Background
MIT Department of Chemistry

Industry
Advanced Materials, Internet of Things

A digital olfactory sensor platform for industry, C2Sense's technology transforms smell into real-time data that can be accessed remotely. With high-fidelity electrochemical sensors at a low price point, C2Sense will empower a broad array of industries including those involved in food supply, power generation, and chemical production to take control of their environments.

Significance
By making gases detectable and trackable on an industrial scale, C2Sense reduces waste, improves safety and health of employees, and builds a more efficient and productive world.

Cambridge Electronics

Founders & Leadership
Bin Lu, Tomás Palacios

Background
MIT Microsystems Technology Laboratories, MIT Department of Electrical Engineering and Computer Science

Industry
Semiconductors, Advanced Materials

Modern-day electronics rely on silicon processing, but Cambridge Electronics aims to bring a revolutionary semiconductor material to the forefront of power electronics and communications. The company's proprietary gallium nitride (GaN) technology is targeted to bring energy savings to electronics for data centers, electric cars, 5G communication, consumer devices—the entire energy processing landscape.

Significance
Cambridge Electronics is transforming a fundamental and ubiquitous technology to help power an exponentially more efficient and exciting future.

Cellino

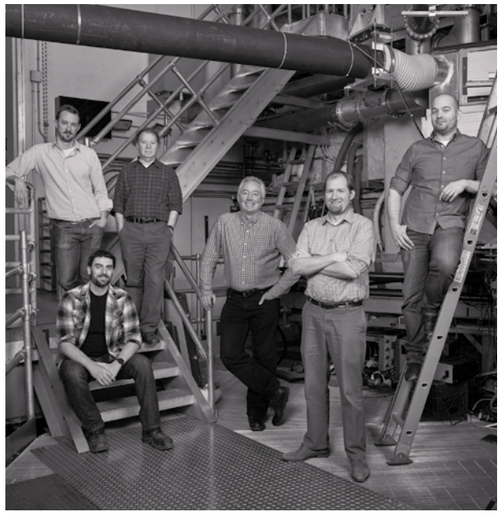
Founders
Nabiha Saklayen, Stan Wang, Matthias Wagner, Marinna Madrid

Background
Harvard Physics Department, Harvard School of Engineering and Applied Sciences (SEAS), Harvard Medical School

Industry
Biotech & Life Sciences, Advanced Manufacturing

The cell therapy industry has great promise to enable the future of medicine, but currently has a massive supply chain problem. Cellino is solving this problem by applying its novel mix of nanotech, optics, and biology to stem cells. Their proprietary delivery technology, NanoLaze, "digitally steers" stem cells to differentiate, creating any cell type at will, with single cell resolution and at high throughput.

Significance
Cellino's platform for the high-throughput digitization of engineering human cells will transform the biotech industry, making cell-based therapies a staple of 21st-century medicine.



Commonwealth Fusion Systems

Founders & Leadership
Zach Hartwig, Brandon Sorbom, Martin Greenwald, Dennis Whyte, Bob Mumgaard, Dan Brunner

Background
MIT Plasma Science and Fusion Center

Industry
Energy, Advanced Materials

Commonwealth Fusion Systems (CFS) aims to provide a new path to fusion power by combining proven fusion physics with revolutionary magnet technology to deploy the first working, economic fusion reactors to the world. The team will develop superconducting magnets based on a new class of high temperature superconductor materials that allow fusion reactors to be 10 times smaller, economically feasible, and operational in the next 10 years.

Significance
Fusion energy is the holy grail of clean energy: limitless, no greenhouse gases, baseload, concentrated, no meltdown, and no proliferation. If successful, the world's energy systems will be transformed.

E25Bio

Founders
Irene Bosch, Lee Gehrke, Bobby Brooke Herrera

Background
MIT Institute for Medical Engineering & Science, MIT Tata Center

Industry
Biotech & Life Sciences

E25Bio has developed a rapid and inexpensive infectious disease response system that detects deadly infectious diseases in minutes, not days, while providing public health officials with the tools to accurately and quickly pinpoint infected areas. Due to its unique antibodies, E25Bio's test is the first of its kind to distinguish between Dengue (as well as all four subtypes of the disease), Chikungunya, and Zika.

Significance
The data generated by the response system will be used to create near real-time portraits of potential epidemics and empower governments to take necessary preventative measures while the spread of disease is still controllable.

Form Energy

Founders
Mateo Jaramillo, Ted Wiley, William Woodford, Yet-Ming Chiang, Marco Ferrara

Background
MIT Department of Material Science and Engineering, 24M Technologies, A123, Tesla Energy

Industry
Energy, Advanced Materials

Form Energy will solve large-scale renewable energy's most fundamental limitation—reliability—through energy storage. Rather than thinking of batteries in the traditional sense, simply as storage vessels, Form is designing bidirectional power plants. Built to displace fossil fuel baseload generation plants, Form Energy's core technology will store and supply hundreds of megawatts via the existing energy grid.

Significance
Form Energy will help usher in a future of humanity's baseload energy from renewable, clean wind and solar power.

HyperLight

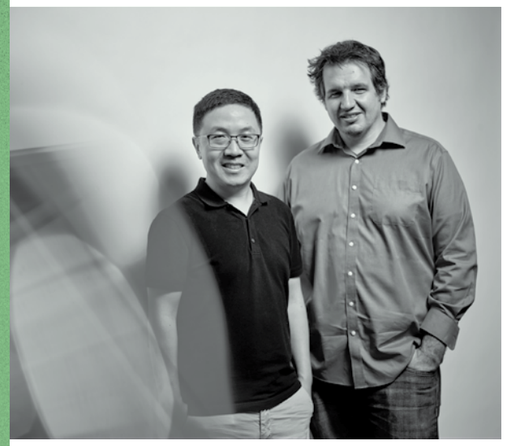
Founders
Mian Zhang, Marko Loncar, Cheng Wang

Background
Harvard University Laboratory for Nanoscale Optics

Industry
Semiconductors, Advanced Materials, Advanced Manufacturing

HyperLight has created a miniaturized version of an electro-optic modulator from lithium niobate (LN). Their invention is chip-size and so efficient that light can propagate in it with near zero loss over one meter. The team also successfully fabricated other high-performance components, such as waveguides, filters, and resonators—all fundamental building blocks of processing information in the optical world.

Significance
Just as optical fiber gave way to the internet and digital communication, HyperLight's technology will empower us to build communication systems with more speed, depth, and efficiency; and enable our newest, most data-intensive technology to flourish.



ISEE

Founders
Yibiao Zhao, Debbie Yu, Chris Baker

Background
MIT Computational & Cognitive Science Group

Industry
Deep Software & AI

ISEE is engineering next-generation, humanistic AI for autonomous vehicles. Their cognitive core can reason through an uncertain future without sole reliance on hand-coded rules or rote pattern recognition. ISEE uses predictive modeling, theory of mind, and probabilistic reasoning to create the cognitive core.

Significance
Built on a cognitive core, ISEE's technology will usher in a world of safe autonomous vehicles, operating without accident and without the need for human intervention.

Kytopen

Founders
Paulo Garcia, Cullen Buie

Background
MIT Department of Mechanical Engineering

Industry
Biotech & Life Sciences, Advanced Manufacturing

Kytopen aims to improve the efficiency of the genetic engineering of cells, regardless of the application. With its microfluidics-based tool, the company can accelerate and automate the genetic engineering of cells 10,000x times faster than current methods, in an automated way. The technology also enables continuous flow genetic manipulation of cells in a platform that can be easily automated and can be used to process both small and large sample volumes.

Significance
The startup's non-viral Flowfect^{TM} solution will reduce the cost and accelerate time to market for discovering and manufacturing next-generation cell and gene therapies.

Radix Labs

Founder
Dhash Shrivathsa

Background
Olin College, MIT Media Lab

Industry
Robotics, Deep Software & AI, Internet of Things, Biotech & Life Sciences

Radix Labs has built a programming language that unites biologists and their lab machinery in one automated unit. This programming language is the heart of software that manages both human and machine tasks. It is the first time disparate lab machinery can communicate with one another under the control of one centralized platform—it is, for all intents and purposes, an operating system for biology labs.

Significance
Requiring no coding and designed around an approachable user interface, this software solution intentionally distances the specification of the program—in this case the lab protocol—from the execution. It does this with the hope that biologists spend less time in the lab, and more time focusing on experimental design and analysis.

Via Separations

Founders
Shreya Dave, Brent Keller, Jeff Grossman

Background
MIT Department of Materials Science and Engineering

Industry
Energy, Advanced Materials, Advanced Manufacturing

Separation processes are the building blocks for materials, chemicals, and consumer goods—they are core to the industrial ecosystem. Currently, separations are done with thermal processes such as evaporation and distillation. Via Separations is commercializing novel membrane materials and manufacturing processes to replace evaporation and distillation with filtration.

Significance
The company's technology has the potential to replace thermal separation, saving the energy equivalent used by the entire gasoline industry every year in the U.S.

Suono Bio

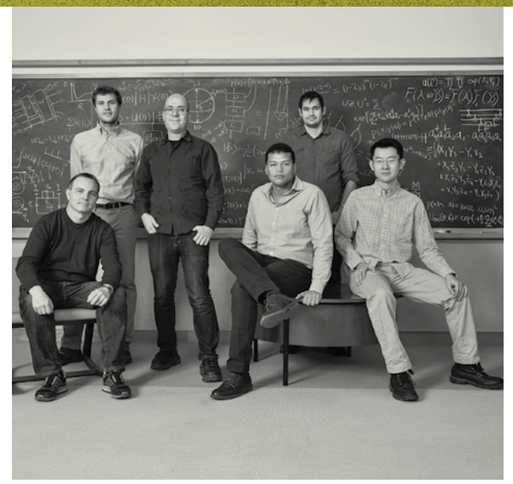
Founders & Leadership
Carl Schoellhammer, Robert Langer, Amy Schulman, Gio Traverso, Lisa Ricciardi

Background
MIT Department of Chemical Engineering

Industry
Biotech & Life Sciences

Suono Bio has reimagined ultrasound as an effective and elegant delivery mechanism for the most delicate therapeutics. Its technology can push molecules like DNA, RNA, and proteins directly into cells without disrupting the surrounding tissue or harming the molecule itself. The flexibility and efficacy of the Suono Bio therapeutic platform brings with it the potential to treat and cure diseases with targets once deemed undruggable.

Significance
Suono Bio will more effectively treat challenging chronic gastrointestinal diseases and enable new therapies for other pressing health challenges like diabetes, cancer, and viral infections.



Zapata Computing

Founders
Christopher Savoie, Alán Aspuru-Guzik, Peter Johnson, Jhonathan Romero Fontalvo, Jonathan Olson, Yudong Cao

Background
Harvard Department of Chemistry, University of Toronto Department of Chemistry

Industry
Quantum Computing

The team of Zapata Computing writes algorithms that harness the power of quantum computing to help predict and simulate some of the universe's most complex interactions, such as the behavior of molecules at an atomic level. When used in tandem with quantum hardware, these algorithms have practical industrial applications, like predicting the structure and the effect of new pharmaceutical compounds before they are synthesized in the lab.

Significance
By creating algorithms that bridge advances in quantum computing hardware and commercial applications, Zapata has the potential of helping discover new life-saving molecules, energy efficient materials, and much more.

Appendix

The Food & Ag Ecosystem in New England

PRIVATE COMPANIES

New England based private Food & Ag companies that have raised a minimum of 1M*
**at least one office*

$3.08B TOTAL AMOUNT RAISED

AGRICULTURAL CHEMICALS / BIOLOGICS
Chemical or biological treatments to environments to increase plant/crop survival, retention, and yield.

PLATFORM
Software services that connect disparate ends of the agricultural/food supply chain.

ANALYTICS
Tools for data analysis in the agrifood tech sector.

CROP / FOOD SCIENCE
Biologically modified food and plants to enhance pest resistance, life span, transportability, production yield.

MECHANICAL & MANUFACTURING
Improvements to mechanical tools or manufacturing processes that make farming or food production/processing/distribution more efficient.

SYNTHETIC ENVIRONMENTS
Non-farm environments for growing plants, livestock, fish.

ROBOTICS / DRONES
Automated machine technology for application of farm additives, food picking/handling/processing and/or observing farm conditions.

SERVICES
Insurance, accounting, consulting, restaurant, retail etc. Services for stakeholders in the agrifood sector (from farmer to consumer).

SENSORS
Novel technology for understanding micro conditions on the farm or in food production/processing facilities, in the soil or in the air that could affect cultivation/ food safety.

WATER UTILITIES
Technologies or services for (waste) water treatment, purification, distribution or dispensation.

FOOD PRODUCTS
Producers, processors and distributors of food products.

PRIVATE COMPANIES

VENTURE / PE BACKED

Agrivida $82.21M
CROP / FOOD SCIENCE
Using GMO to improve the nutritional content of animal feed.

American Robotics $3.1M
ROBOTICS / DRONES
Developer of industrial drones designed for season-long crop scouting at farms.

Analytical Space $4.47M
ANALYTICS | PLATFORM
Provider of space telecommunication services for faster or more data-downloads from space, with applications in e.g. precision agriculture.

B.Good $5.16M
FOOD PRODUCTS | SERVICES
Operator of an innovative, fast casual and farm-to-table restaurant chain.

Bevi $64.03M
WATER UTILITIES
Developer of collapsible and reusable water delivery kiosks designed to eliminate waste from the production, shipping, and disposing of bottled beverages.

Biobot Analytics $2.64M
ANALYTICS
Providing a wastewater analysis tool to extract valuable data from urban waterways.

Bloom Automation $1.03M
ROBOTICS / DRONES
Provider of human-collaborative robotic technology to automate commercial and medicinal cannabis cultivations.

Cambrian Innovation $17.18M
WATER UTILITIES
Provider of distributed wastewater treatment and resource recovery services to mitigate environmental and economical risk.

Cambridge Crops $1.3M
AGRICULTURAL CHEMICALS / BIOLOGICS
Developer of a life-extending edible coating for perishable foods.

C16 Biosciences $4.22M
CROP / FOOD SCIENCE
Developer of technology designed to brew a sustainable alternative to palm oil from microbes.

C2Sense $4.7M
SENSORS | ANALYTICS
Developer of a gas sensing technology to transform smell into real-time data, with applications for i.e. The Food & Ag industry.

Cibo Technologies $38.22M
ANALYTICS | PLATFORM
Developer of a software platform to simulate complex agricultural ecosystems.

Climacell $70.23M
ANALYTICS | PLATFORM
Developer of a hyper-local weather forecasting platform with applications in e.g. precision agriculture.

PRIVATE COMPANIES

Clover Food Products $17.13M
SERVICES
Operator of restaurant chains and food trucks offering sandwiches and homemade popovers.

Crop Enhancement $14.5M
AGRICULTURAL CHEMICALS / BIOLOGICS
Developer of environmentally friendly chemistries to minimize pesticide use.

Crop One Holdings $18.32M
SYNTHETIC ENVIRONMENTS | PLATFORM
Provider of a vertical farming and sustainable technology platform to facilitate indoor growing.

Drizly $70.33M
SERVICES | PLATFORM
Developer of an online liquor retail platform.

Emulate $93M
CROP / FOOD SCIENCE | ANALYTICS
Engineering organ-on-chips to predict how humans may respond to chemicals, medicines and foods.

Enko Chem $13.5M
AGRICULTURAL CHEMICALS / BIOLOGICS
Developer of technology to discover and develop new crop protection chemistries.

Franklin Robotics $1M
ROBOTICS / DRONES
Developer of solar-powered robots designed to remove plant weeds.

Freight Farms $12.98M
SYNTHETIC ENVIRONMENTS
Manufacturer of container farms to create local produce ecosystems on a global scale.

Fresh Nation $13.31M
PLATFORM
Provider of an online supply portal designed to connect grocery store chains, distributors and e-commerce grocers with locally produced food.

Geovantage $1.11M
ANALYTICS | SENSORS
Provider of aerial imagery technology, with applications in i.e. precision agriculture.

Ginkgo Bioworks $437.45M
AGRICULTURAL CHEMICALS / BIOLOGICS
Biologically engineering custom microbes for applications in Life Sciences, Agtech, Cosmetics and more.

Greenlight Biosciences $141.55M
AGRICULTURAL CHEMICALS / BIOLOGICS
Developer of RNAi-based technologies to allow for sustainable biological alternatives to chemical pesticides.

GreenSight Agronomics $2.6M
ANALYTICS | ROBOTICS / DRONES | SENSORS
Providing an automated intelligence platform to help golf courses and the agricultural industries reduce water and chemical costs.

Harvest Automation $27.89M
ROBOTICS / DRONES
Developer of robots to perform material handling tasks in the agricultural industry.

PRIVATE COMPANIES

Harvest Power $259.24M
AGRICULTURAL CHEMICALS | SERVICES
Provider of services including the production of renewable energy (e.g. natural gas and engineered fuels) and soil enhancement products (e.g. fertilizers) from discarded organic materials.

Inari Agriculture $58M
CROP / FOOD SCIENCE | PLATFORM
Developer of plant breeding technologies to allow for predicable and affordable growing.

Indigo Agriculture $620.63M
AGRICULTURAL CHEMICALS / BIOLOGICS | PLATFORM
Provider of plant microbiome agricultural services designed to increase crop yield + digital platform to connect growers and buyers.

InnovaSea Systems $15.19M
SYNTHETIC ENVIRONMENTS
Developer of next generation integrated open ocean aquaculture farming systems.

KnipBio $5.87M
AGRICULTURAL CHEMICALS/BIOLOGICS | FOOD PROD.
Developer of premium nutritious protein for animal feeds from sustainable, abundant feedstock such as ethanol and methanol, using microbe strains.

Kula Bio $1M
AGRICULTURAL CHEMICALS / BIOLOGICS
Creating microbes that release fertilizer to the soil over a prolonged period of time.

Liquiglide $23.1M
MECHANICAL & MANUFACTURING
Developer of surface coatings to make viscous liquids slide easily, reducing waste.

Manus Bio $20.02M
AGRICULTURAL CHEMICALS / BIOLOGICS
Developer of an advanced fermentation technology to biomanufacture complex natural products.

Motif Ingredients $90M
CROP / FOOD SCIENCE
Biologically engineering custom microbes for applications in Food (plant-based).

Promethean Power Systems $1.01M
MECHANICAL & MANUFACTURING
Manufacturer of rural refrigeration systems to offer cold-storage in off-grid and partially electrified areas of developing countries.

Root AI $2.3M
ROBOTICS / DRONES
Developer of AI-powered robotics technology with a focus on indoor farming.

Sandymount $3.45M
MECHANICAL & MANUFACTURING
Provider of a filtration technology designed to reduce the water content from beverages before shipping.

Smart Lunches $15.26M
FOOD PRODUCTS | PLATFORM | SERVICES
Provider of an online platform to offer food ordering service for children in school.

Soft Robotics $29.32M
ROBOTICS / DRONES
Developer of robotic end-of-arm grasp tools to automate industries such as food&beverage, advanced manufacturing and e-commerce.

Spyce $24.88M
ROBOTICS / DRONES | SERVICES
Developer of a fully robotic kitchen designed to revolutionize the fast food industry.

Understory $17.4M
ANALYTICS
Developer of smart weather station micro-grids for accurate weather forecasting based on real-time data, with potential applications in e.g. precision agriculture.

Spoiler Alert $5.15M
ANALYTICS | PLATFORM
Developer of software solutions to optimize the food supply chain, manage inventory and minimize surplus.

Yasso $14.61M
FOOD PRODUCTS
Producer and seller of frozen yogurt novelties.

CORPORATE BACKED

Joyn Bio $100M
AGRICULTURAL CHEMICALS / BIOLOGICS
Biologically engineering custom microbes for applications in Agtech *(soil microbiome)*.
Bayer-Gingko Bioworks Joint Venture. Sept 2017.

Telluslabs N/A
ANALYTICS
Turning satellite data into insights and actions using machine learning, applied to agriculture.
Acquired by Indigo Agriculture for an undisclosed amount. *(Previously raised 3.1M in VC)*. Dec 2018.

Stonyfield Farm $875M
FOOD PRODUCTS
Producer and seller of dairy products intended to offer healthy food items, primarily organic yogurt.
Acquired by Lactalis Group. August 2017.

Incredible Foods N/A
FOOD PRODUCTS | MANUFACTURING
Manufactures and seller of non-dairy frozen products. Received an undisclosed amount of financing from Skyviews Life Science on Oct 2018.

OTHER PRIVATES

Beantrust N/A
SERVICES
Offering coffee consulting services, organizing tasting events, provider of whole bean coffee from sustainable farms, as well as curated teas and chocolates.

Chew Innovation N/A
SERVICES | FOOD PRODUCTS
Innovation lab focused on food and beverage industry, partnering with companies to create delicious, nutritious, profitable, sustainable and scalable products.

One Mighty Mill N/A
FOOD PRODUCTS | SERVICES
Provider of local, stone-ground flour.

PRIVATE COMPANIES

Natural Products Consulting N/A
SERVICES
Consulting service company providing assistance in bringing natural, organic and specialty products to market.

Northbound ventures N/A
SERVICES
Consulting service company to assist the development of sustainable communities and regional food systems.

State Garden N/A
FOOD PRODUCTS | SERVICES
Supplier of organic and conventional tender leaf greens, spinach and celery hearts.

INVESTOR

Investors with a presence in New England that have made at least one Food & Ag investment.

$111.08B TOTAL AUM

FOUNDATIONS AND ANGELS

Branch Venture Group N/A
FOOD & AG
Angels: majority early stage
Example: Ocean Approved

The Fink family Foundation $14.95M
CLEANTECH | FOOD & AG
Non-profit private foundation: grants+equity investments: majority early stage
Example: Spoiler Alert

INSTITUTIONAL VENTURE CAPITAL

Anterra Capital $200M
FOOD & AG
Early stage + later satge
Example: Enko Chem

BASF Venture Capital $262.14M
CHEMISTRY | MATERIALS | DIGITIZATION | NEW BUSINESS MODELS
Early stage + later stage
Example: Arcadia Biosciences

BioGenerator N/A
HEALTH AND PLANT SCIENCES
Majority early stage
Example: Arch Innotek

Breakthrough Energy Ventures $1.1B
CLEANTECH
Majority early stage
Example: Motif

Flagship Pioneering $2.82B
MAJORITY BIOTECH/LIFE SCIENCES | FOOD & AG
Majority early stage
Example: Inari

Flybridge Capital Partners $625M
TECH
Early stage + later stage
Example: Imperfect Produce

INVESTOR

Fresh Source Capital $10M
FOOD & AG
Majority early stage
Example: Agrilyst

NEA $18B
TECH | CONSUMER | ENERGY | HEALTHCARE
Early stage + later stage + growth/expansion
Example: Waterbit

Raptor Group $61M
TECH | CONSUMER | SPORTS&MEDIA | FINANCIAL SERVICES | HEALTHCARE
Early + later stage + growth/expansion
Example: Yasso

Rhapsody Venture Partners $22M
TOUGH TECH
Majority early stage
Example: Manus Bio

Romulus Capital $200M
GENERAL
Early stage + later stage
Example: Ceres Imaging

SOSV $386.8M
HARDWARE | BIOTECHNOLOGY | FOOD | E-COMMERCE
Majority early stage
Example: Memphis Meats

Spark Capital $3B
MEDIA | SOFTWARE | TECH
Early stage + growth/expansion
Example: Full Harvest

Supply Chain Ventures N/A
SUPPLY CHAIN
Majority early stage
Example: Sandymount

Tabard Venture Capital
AGTECH
Majority early stage
Example: Greensight Agronomics

The Engine $205M
TOUGH TECH
Majority early stage
Example: Cambridge Crops

HEDGE FUND

Viking Global Investors $28.8B
GENERAL, MAJORITY BIOTECH/LIFE SCIENCES
Majority growth/expansion
Example: Impossible Foods

CORPORATE VENTURE CAPITAL

Alexandria Venture Investors $750M
MAJORITY BIOTECH/LIFE SCIENCES | FOOD & AG
Majority early stage
Example: AgriMetis

Novo Holdings $55.92B
BIOTECH/LIFE SCIENCES
Early stage> later stage
Example: BioPhero

GV $2.33B
CONSUMER | TECH | LIFE SCIENCES
Early stage + later stage
Example: Benson Hill Biosystems

INVESTOR

REAL ESTATE

Hancock Agricultural Investment Group $2.5B
Real estate: invests in farmland properties.

PUBLIC COMPANIES*

New England based public Food & Ag companies (Market cap in USD, based on data from 4/15/19)*
**At least one office*

$108.68B MARKET CAP, USD 4/15/19

Bayer $64.10B
AGRICULTURAL CHEMICALS / BIOLOGICS
Healthcare and agriculture conglommerate; its crop science business includes seeds, pesticides, herbicides, fungicides, which has expanded after the acquisition of Monsanto in June 2018.

BGI $4.29B
ANALYTICS | SERVICES
Provider of genomic class diagnosis and research services using biotechnology, focused on agriculture and food science and human health.

Future Farm Technologies $18.48M
SYNTHETIC ENVIRONMENTS
Operator and developer of indoor cultivation methods, processing, retail and technology, focused on cannabis.

Ocean Spray Cranberries N/A
FOOD PRODUCTS
Agricultural cooperative grower of cranberries and grapefruit.

Silgan Holdings $3.34B
MECHANICAL & MANUFACTURING | FOOD PRODUCTS
Manufacturer of metal food containers/packaging (manufactures half of metal food containers in North America).

Standex $945.82M
MECHANICAL & MANUFACTURING | FOOD PRODUCTS
Manufacturer of variety of products for several commercial and industrial markets, among others.

Sysco $35.43B
SERVICES | FOOD PRODUCTS
Leading food-service distributor, controlling around 16% of nearly $300B market segment.

Wismettac $539.49M
SERVICES | FOOD PRODUCTS
Food distribution company, with 3 business units: Asian Food Global Business, Agricultural and Seafood Products Business and Amentiy Food and Retail Business.

Yield10 Bioscience $15.06M
CROP / FOOD SCIENCE
Developer of disruptive technologies for step-change improvements in crop yield for food and feed crops to enhance global food security.

ACADEMIC INITIATIVES

BABSON COLLEGE

Babson College FoodSol
Action tank for food entrepreneurship of all kinds.

BOSTON COLLEGE

Boston College: Innovation in Urban Science Education
Designing STEM learning environments, one focus area is AgTech entrepreneurship | hydroponics program funded by USDA/NIFA.

HARVARD

Harvard Alumni for Agriculture
Professional organization of prominent alumni working in agriculture, food and other adjacent industries.

Harvard Food Better
Harvard University Center for the Environment; events, dialogs community, centered around how to make food better (grow, eat, shop).

Harvard Food Policy Group: PAPSAC
Private and Public Science, Academic, and Consumer Food Policy Group.

Harvard Law School: Food Law and Policy Clinic
Provides students with the opportunity to practice using legal and policy tools in order to address the health, environmental, and economic impacts of our food system.

Harvard Office for Sustainability
Built a roadmap to lead to a more sustainable campus community.

MIT

MIT Climate Co Lab
Open problem-solving platform where a growing community of over 115,000 people work on plans to reach global climate change goals.

MIT DiSTAP (SMART)
Research program under Singapore-MIT Alliance for Research and Technology for Disruptive and Sustainable Technology for Agricultural Precision.

MIT Food and Agriculture Club
Brings together students — and other MIT community members — to coordinate and support work in the areas of food and agriculture.

MIT Food Insecurity Solutions Working Group
Community members assessing the problem and generating ideas for addressing student hunger.

MIT Energy Club
Connects students, alumni, and community members who are passionate about energy.

MIT J-WAFS (Abdul Latif Jameel Water and Food Systems Lab)
Institute-wide effort to bring MIT's unique strengths to bear on the world's diverse needs for water and food, given climate change, urbanization, population growth, development.

ACADEMIC INITIATIVES

MIT Open Ag
The MIT Media Lab Open Agriculture Initiative (OpenAg) builds open resources to enable a global community to accelerate digital agricultural innovation.

MIT Sloan School of Management Sustainability Initiative
Provides education, community, dialogue, tools to lead to actions that will allow humans and nature to thrive for generations to come.

MIT WATER
Premier network for water research and innovation at MIT, connecting students with industry experts.

TUFTS

Tufts Gerald J. and Dorothy R. Friedman School of Nutrition Science and Policy
Focused on molecular nutrition, human metabolism, population studies, clinical trials, nutrition interventions and behavior change, communication, food systems and sustainability, global food insecurity, humanitarian crises, and food economics and policy.

U MASS AMHERST

UMass Amherst, Center for Agriculture, Food and the Environment
Integrating research and outreach education in Food & Ag.

GOVERNMENT PROGRAMS

City of Boston Food Access Urban Ag Visioning
CITY
Aims to bring private, public and non-profit organizations to the table to create a vision for urban food production and distribution.

Feed The Future
STATE
US Government's Global Hunger and Food Security Initiative to address the root causes of poverty, hunger and malnutrition.

Agricultural Energy Grant Program (ENER)
STATE
Funds agricultural energy proucts to improve energy efficiency and adoption of alternative energy by Massachusetts farms.

MassCEC grants
STATE
Various Grant Program to support cleantech companies along their lifecycle. Cambridge Crops received catalyst grant.

NSF grants
FEDERAL
E.g. BREAD grant was awarded to URI to develop unisexual flowers in rice.

USDA - NIFA
FEDERAL
E.g. funded UNH program on pollinator health and plant breeding.

COMMUNITY BUILDING AND MORE

Agtech Nexus
Industry conference convening an international group of investors, agribusiness executives, agtech entrepreneurs and farmers with a spotlight on the rapidly growing agriculture technology market. 2018 conference was in Boston, 2019 in Chicago

Artscience Culture Lab and Cafe
Founded by David Edwards in 2014, ArtScience is a café and culture lab committed to great casual drinks and dining alongside art, science, and design experiences that express audacious frontier dreams of tomorrow.

Bayer LifeHub Boston
LifeHub AgConnect: monthly community gatherings to discuss Ag-related topics; regular co-creation sprints.

Bevnet Live
Beverage industry news, reviews, events, jobs. Headquartered in Boston.

Branchfood
Seeks to promote food entrepreneurship and support the community of founders launching and scaling transformative businesses. We strive to cultivate community, inspire innovation, and elevate New England as a leading food hub.

Cambridge Food Lab
Community building/support for food entrepreneurs.

FoodEdge
Conference organized by Branchfood: two days of keynotes, innovation workshops, and fireside chats, and nearly 400 attendees, to explore the trends, strategies and capabilities that will transform food as we know it.

Global Summit on Agriculture, Food Science and Technology
Conference on sustainable Agriculture Technology to eliminate global food shortage. 2018 edition organized in Boston.

New Harvest
Annual New Harvest Conference at MIT Media Lab to explore the opportunities, challenges, and realities of cellular agriculture.

Nutter Uncommon Law
Hosts annual Founder Roundtable for High Growth Food and Beverage Entrepreneurs.

Revision Urban Farm
Community-based urban agriculture project that grows produce in its own fields and provides access to affordable, nutritious and culturally appropriate food to residents of our ReVision Family Home and our extended community.

Slow Food
Boston chapter of international food movement focused on providing good, clean, fair food for all.

Sustainable Food Lab
Non-profit organization to help organizations implement innovations in sustainability in the mainstream food system.

COMMUNITY BUILDING AND MORE

Target FoodFuture CoLab
In Cambridge MA, set up with the help of IDEO and MIT Media Lab. This initiative was closed in 2017.

The Food Project
Non-profit organization that aims to engage young people in personal and social change through sustainable agriculture.

Urban Farming Institute
The Urban Farming Institute of Boston's mission is to develop and promote urban farming as a commercial sector that creates green collar jobs for residents; and to engage urban communities in building a healthier and more locally based food system.

Venture Cafe Cambridge
Offers networking, theme nights, programming, to connect entrepreneurs, investors, and innovators, organizing foodbev connect 2019.

PRIZES/ACCELERATOR/ INCUBATOR

Greentown Labs
CLEANTECH/ENERGY FOCUS
Accelerator/incubator

MIT 100k
GENERAL
Business plan competition

Mass Challenge
GENERAL
Accelerator/incubator

Mass Robotics
ROBOTICS
Accelerator/incubator

MIT Sandbox Innovation Program
GENERAL
Accelerator/incubator, MA

MIT Solve
GENERAL
Solve seeks solutions from tech innovators around the world for its annual Global Challenges.

Rabobank MIT Food and Agribusiness Innovation Prize
FOOD AND AGRIBUSINESS
Business-plan competition for MIT university and graduate students.

Techstars Boston
GENERAL
Accelerator/incubator

The Food Loft
FOODTECH
Co-working space + some investments, MA

Tough Tech Summit℠ 2019

October 21 & 22
Hotel Commonwealth
Boston

Our second invite-only conference of founders, entrepreneurs, investors, academics, and business leaders will explore the challenges of bringing Tough Tech to market, and how the ecosystem can work together to accelerate commercial success of world-changing technologies.

THE ENGINE
Built by MIT

Tough Tech has a community,

it has stewardship,

and it has a home — The Engine

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