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By Eric Lipton Photographs and Video by Amir Hamja
Eric Lipton reported from Iowa, Illinois, Missouri and Massachusetts, touring corn farms, a fertilizer plant and laboratories as scientists work to combat climate change by revamping how corn is grown.

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With the push of a red button, a milky-colored liquid sprayed onto a load of corn seed at a warehouse in central Missouri. It was a hint of a revolution underway in American agriculture, driven by a desire to combat climate change while still feeding and fueling the world.

Inside that liquid were bacteria whose DNA had been altered so that once the corn seeds are in the ground, the bacteria create extra nutrients for the plants. That could greatly reduce the need for the chemical fertilizers that dominate modern agriculture and are a source of the pollution that is heating the planet.

As the dangers of climate change become more apparent, scientists and entrepreneurs are exploring ways to engineer natural systems to reduce greenhouse gases.

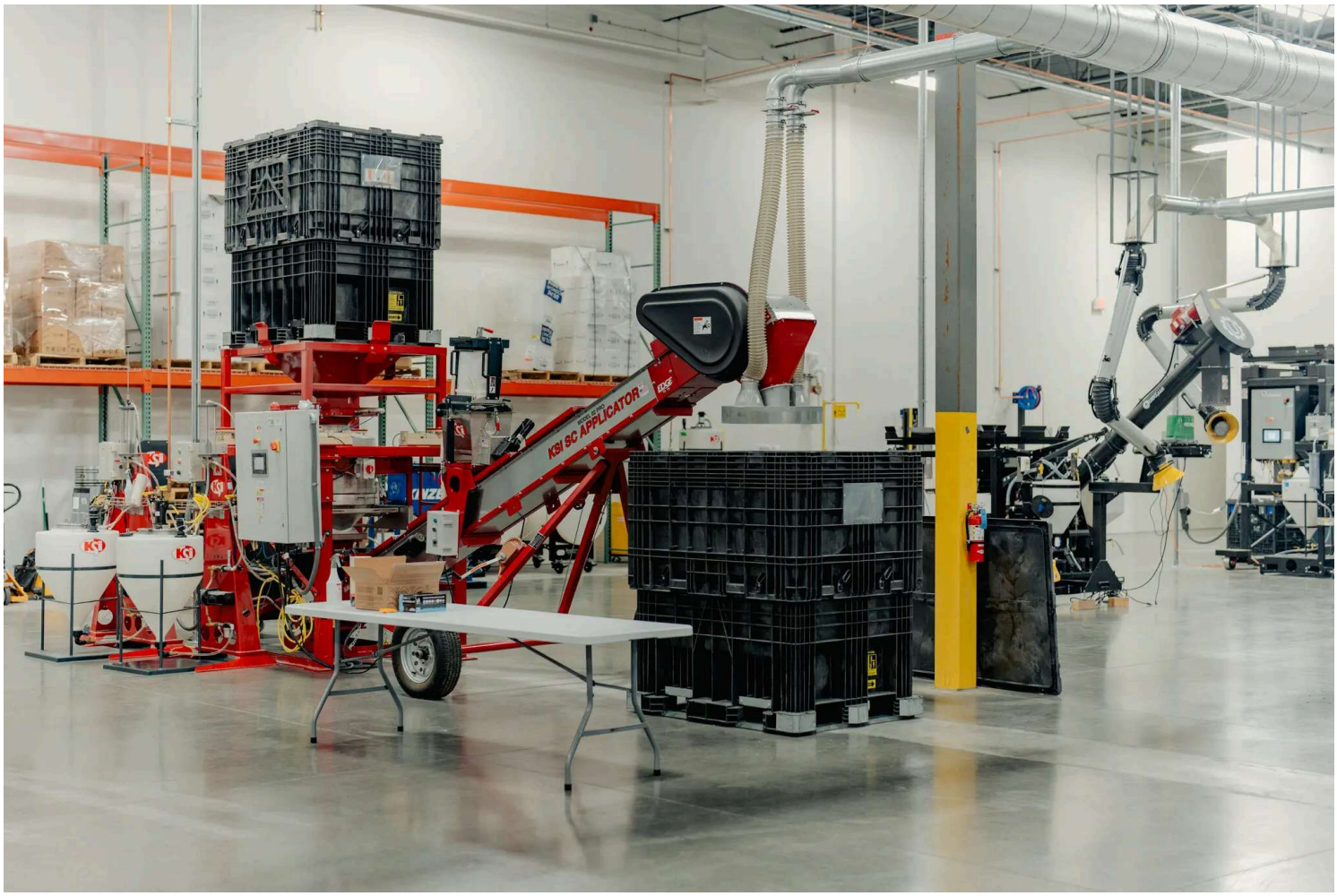
A $200 billion industry dominated by a few global giants like Koch Industries, chemical fertilizer is made by mixing nitrogen from the air with hydrogen from natural gas at high temperatures and pressure to create ammonia. The ammonia is turned into ammonium nitrate, which is injected into the soil or spread onto corn, wheat and rice fields to help them grow.

Chemical fertilizer is credited with helping to produce enough food for a world population that has ballooned from about 1.6 billion in 1900, when the process was created, to about 8 billion today.

But it has also added to the climate crisis in two ways.

Making fertilizer produces carbon dioxide, which traps heat from the sun. When it's spread on soil, a portion of that fertilizer is released into the air as nitrous oxide, a greenhouse gas many times more potent than carbon dioxide.

Globally, the manufacture, transportation and use of chemical fertilizer is responsible for pollution with the equivalent planet-warming power of about 1 billion metric tons of carbon dioxide each year. That's more than the combined releases from all the coal-burning power plants in the United States.



The seed and microbe mixer of the Pivot Bio plant.

A test field of corn plants treated with Pivot Bio's DNA-modified bacteria in Harvel, Ill. At this point, the Pivot product can replace about 20 percent of the fertilizer needed on a corn field.

That's why corn seeds in Illinois, Iowa and other corn-belt states are being sprayed with genetically modified bacteria manufactured by Pivot Bio, a California-based company. Pivot, whose investors include groups led by Bill Gates and Al Gore, has been embraced by farmers looking to spend less on fertilizer. Just five years after they were introduced, the seeds are being used on 5 percent of American corn crops.

The company has faced barriers to selling its product in Europe but after aggressive lobbying in Washington, Pivot successfully has argued along with other industry players that its products do not require a safety review by American regulators.

Pivot estimates that last year, its treated seeds prevented the release of an estimated 706,000 metric tons of carbon dioxide equivalent — comparable to the greenhouse gases from burning 1.5 million barrels of oil.

“This has been a holy grail for the farming industry,” said Cooper Rinzler, a partner at Breakthrough Energy Ventures, the investment fund backed by Mr. Gates that was an early investor in Pivot.

But it’s also producing intense pushback.

An unusual coalition of interests that includes an organic farming group, the environmental organization Friends of the Earth and the conspiracy theorist Alex Jones argues that supercharging nature by rewriting the genetic code could have unintended consequences. Manufacturers of chemical fertilizer are also raising doubts about the new industry player.

Pivot’s own advisers concede there are unanswered questions.

“We have rarely created a solution to an environmental problem that doesn’t create other unforeseen consequences down the line,” said David Kanter, a Pivot adviser who teaches environmental studies at New York University and chairs the International Nitrogen Initiative, an effort to reduce global emissions from fertilizer. “One of the big concerns around any kind of genetic engineering is what happens when it leaves its intended site. How long do these microbes stay active?”

Scientists at Pivot said the genetically modified bacteria die when the corn plant dies, limiting the risk of unintended spread. But they did not provide evidence that all of it dies each year. And they insist that their effort to manipulate nature is a win for farmers, the growing global population and the environment.

“Farmers, by using our products, we will get cleaner air, cleaner water, healthier soil and the ability to feed the planet,” said Karsten Temme, Pivot’s co-founder. “That’s always been my dream.”

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Voigt Lab at the Massachusetts Institute of Technology looks like any other laboratory: petri dishes, incubators and hundreds of small bottles. But a radical effort to engineer nature to fight climate change is underway there.

Philip Clauer, right, a doctoral student in Christopher Voigt's M.I.T. lab. "Design, build, test, repeat," he said of work to advance seed science.

The work has its origins about two decades ago, when Christopher Voigt, a biologist and engineer, took apart a Texas Instruments calculator.

He deconstructed its computer chip and figured out a way to enter the computer code into a DNA sequencing program. Instead of designing a new chip, he emerged with a DNA sequence that could be edited into bacteria cells and program them to

line up in petri dish in a predetermined sequence of colors, lighting up like a calculator's display.

Dr. Voigt became a rock star of sorts in the fast-growing field of biological engineering — changing biological processes to create living systems that function in ways that do not already exist in nature.

Fertilizer was a natural target for this transformative technology.

As far back as 1975, scientists had been trying to revamp the way crops are grown to produce more food with less chemical fertilizer.

Nature, on its own, already does some of this work. Microbes in soil feed off sugars expelled by corn roots and then turn nitrogen in the air into food for the corn crop. But once factory-made fertilizer is spread on a field, the microbes detect its presence and turn off.

Pivot's product, with a series of tweaks to its DNA, effectively hijacks the microbe and forces it to keep producing nitrogen, and at a much faster rate.

Still, it's not enough.

Pivot's altered bacteria can replace about 20 percent of the fertilizer needed on a cornfield; the goal is to supplant as much as half the fertilizer used today. Other companies, including Ginkgo Bioworks and BioConsortia, are developing their own versions. Academics at M.I.T. and other universities are trying to make further advances. At this point, scientists don't believe they can completely eliminate the need for chemical fertilizer.

One recent afternoon, Phillip Clauer, 27, one of Dr. Voigt's doctoral students, was dropping liquids with different genetic modifications into test tubes, in the quest to improve Pivot's product.

"Design, build, test, repeat," Mr. Clauer said.

At Pivot's laboratories in California, scientists are using artificial intelligence to run through thousands of possible DNA configurations for the bacteria, before choosing candidates to test in cornfields.

A.I. allows them to dramatically speed up the work, said Dr. Temme, whose company has raised nearly $700 million in venture capital, and now has an estimated valuation of $1.7 billion, according to PitchBook, a database of startups.

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In the southeast corner of Iowa, near the Mississippi River, a factory rises out of the cornfields. It's a behemoth, a 320-acre industrial site that consumes so much natural gas, it connects directly to a pipeline carrying fuel from Texas and Louisiana.

Product stored at the Iowa Fertilizer Plant in Wever, Iowa.

The Iowa Fertilizer Company, owned by Koch Industries, runs 24 hours a day, seven days a week, annually pumping out 2 million tons of nitrogen fertilizer each year.

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Everything about the factory is super sized. It consumes enough natural gas to heat an estimated 380,000 homes. It sucks up 1.6 billion gallons of water each year — the amount used by Ames, Iowa, population 60,000.

On a recent tour, a reporter looked inside a gas furnace that heats up to 2,000 degrees Fahrenheit to break the bonds of the atmospheric nitrogen, as the plant starts the process of creating ammonia, which continues through a maze of pipes and tanks.

It is dangerous work; ammonium nitrate is explosive and has been used in bombs and weapons. Fritz Haber, the Nobel Prize-winning German scientist who figured out the chemistry needed to make synthetic fertilizer, is credited with both feeding billions and killing tens of millions, as munitions and chemical weapons since at least World War I also relied on his inventions.

“It’s one of the most incredible, important inventions in the history of humanity because it feeds the planet,” said Dr. Rinzler of Breakthrough Energy Ventures, of the 111-year-old process of manufacturing fertilizer. “But it is also a giant emissions challenge.”

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Like most farmers, Jim Purlee is always in search of greener, taller and plumper plants to produce bigger cobs of corn. That’s why, with the exception of those following organic practices, almost all farmers for decades have used enormous amounts of chemical fertilizer.

“You must have nitrogen to make more bushels of corn,” Mr. Purlee, 74, whose family owns about 3,000 acres in western Illinois, where his family has been farming since 1835.

Two years ago, he started to use Pivot’s treated seeds that are coated with the genetically modified bacteria. The result, he said, has been more robust plants grown with less fertilizer. An acre of corn typically uses about 180 pounds of chemical fertilizer; Mr. Purlee was able to shave off 40 pounds by using Pivot’s product.

Like many other Illinois farmers, he is growing corn to make ethanol, which is blended into gasoline.

The biological revolution taking place in Mr. Purlee’s cornfields is not easy to see. The microbes are silently working in the soil, little biological engines that have been reprogrammed to keep producing ammonia even after he had treated his fields last fall with chemical fertilizer.

In an experimental field nearby, Pivot has created a kind of before and after display. In one section, plants are grown with only chemical fertilizer. Next to it are corn stalks planted with the treated seeds, and less fertilizer. The difference is visible. The plants from treated seeds are greener, fuller and their cobs are larger.

A corn plant grown from untreated seed, left, and corn treated with Pivot Bio's product.

Farmers have been crossbreeding plants for centuries, a form of genetic modification, to improve results.

But changing the genetics of bacteria in the soil raises new concerns. Kendra Klein, deputy director for science at Friends of the Earth, noted that there could be trillions of altered bacteria in one acre of corn, making containment impossible.

“We are engineering organisms to do things that nature has not designed them to do and releasing them, in the billions, into incredibly complex ecosystems,” she said. “It is more scientifically reasonable to assume that there will be unintended consequences than to assume that everything will go well.”

Conservative and religious groups have piled on. Alex Jones has suggested that the “modified soil microbes could trigger a genetically engineered doomsday.”

Some researchers, with support from trade associations funded by Koch Industries and other companies that make fertilizer, have also questioned Pivot’s work. They say the treated seeds are not increasing crop yields, although that was never one of Pivot’s goals.

Emerson Nafziger, a retired University of Illinois professor whose continuing research is often sponsored by the industry-funded Illinois Fertilizer & Chemical Association, said Pivot’s product seems more hype than substance.

Dave Franzen, an agronomist at North Dakota State University, who has worked with Dr. Nafziger, said he wonders whether the Pivot Bio microbes would produce excess nitrogen, which can run off fields into nearby rivers and lakes to create fish-killing algae blooms and contaminate drinking water. “I have a little bit of misgiving about biotech and bioengineered microbes,” he said. “You can’t really turn them off.”

Pivot wants to expand to other markets, including Canada and Brazil. Regulators in the European Union, which is conservative when it comes to genetic manipulation, have withheld approval and sought more data on the safety of modified microbes.

Christopher Voigt, a biologist and engineer at M.I.T.

In Dr. Voigt's lab. Fighting climate change means embracing new technology, he said.

The company has worked aggressively in Washington to avoid a similar situation in the United States. In 2020, the company sent a letter to the Agriculture Department, arguing that it was exempt from regulatory review. Federal rules require a review when a genetic modification is the result of transferring DNA from one organism to another. In Pivot's case, changes were made to DNA already found in the bacteria. The department accepted that rationale less than two weeks later, agency documents show.

The company also lobbied the White House, the Environmental Protection Agency and members of Congress, as it attempted to avoid additional regulation of its products and sought federal incentives for farmers to buy it, records obtained by The New York Times show.

Back at M.I.T., research continues. In a greenhouse hidden on the seventh floor of an academic building, members of Dr. Voigt's team are modifying the genetics of potato and tobacco plants so they might someday feed themselves by directly converting nitrogen in the air into nutrients.

Dr. Voigt said opposition to the work makes little sense.

"Basically you have to pick here," he said. "Greenhouse gas emissions or the use of a genetically modified organism. You have to make a choice. You can't address the challenge without technology."

Eric Lipton is an investigative reporter, who digs into a broad range of topics from Pentagon spending to toxic chemicals. More about Eric Lipton

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