How green are biofuels? Does corn-derived ethanol promote sustainability?

Tyler Lark, a geographer at the University of Wisconsin-Madison, grew up among farms, working on a neighbor's dairy, vaguely aware of the tension between clearing land to grow food and preserving nature. As an engineering student working on water projects in Haiti, he saw an extreme version of that conflict: forests cleared for firewood or to grow crops, producing soil erosion, environmental denudation and worsening poverty. "I think it was that experience that told me, 'Hey, land use is important,'" he says.

knowablelogo e x He decided to study how farmers transform landscapes through their collective decisions to plow up grasslands, clear trees or drain wetlands — decisions that lie at the heart of some of the planet's greatest environmental challenges, and also provoke controversy. Lark carries professional scars from recently stumbling into one of the fiercest of these fights: the debate over growing crops that are used to make fuel for cars and trucks.

About 15 years ago, government incentives helped to launch a biofuel boom in the United States. Ethanol factories now consume about 130 million metric tons of corn every year. It's about a third of the country's total corn harvest, and growing that corn requires more than 100,000 square kilometers of land. In addition, more than 4 million metric tons of soybean oil is turned into diesel fuel annually, and that number is growing fast.

Scientists have long warned that biofuel production on this scale involves costs: It claims land that otherwise could grow food or, alternatively, grass and trees that capture carbon from the air and provide a home for birds and other wildlife. But government agencies, relying on the results of economic models, concluded that those costs would be modest, and that replacing gasoline with ethanol or biodiesel would help to meet greenhouse gas reduction goals.

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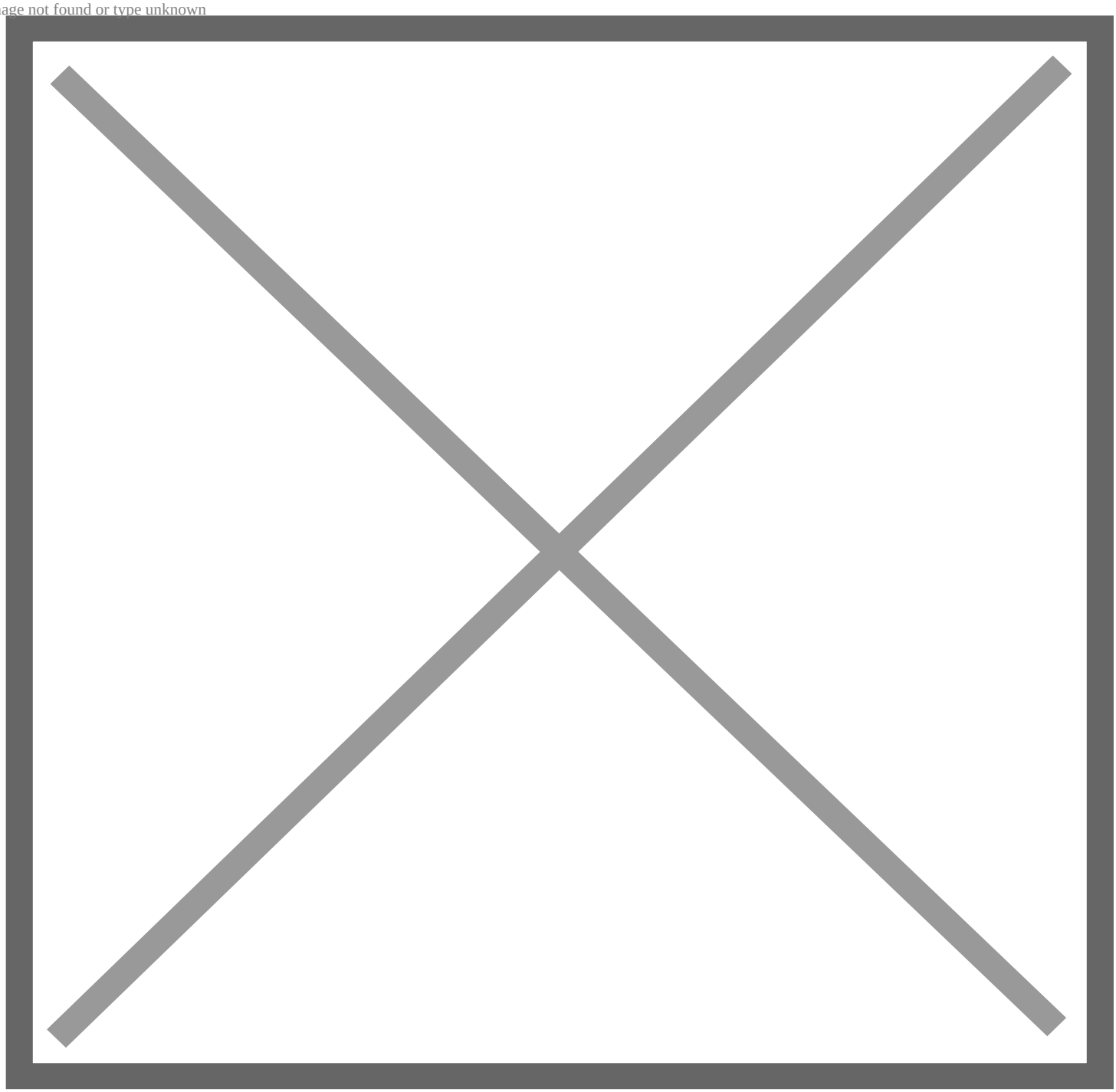

Lark and a group of colleagues recently jolted this debate back to life. In a February 2022 study, they concluded that the law that unleashed the ethanol boom persuaded farmers to plant corn on millions of acres of land that would otherwise have remained grassland. Environmentalists had long feared that biofuel production could lead to deforestation abroad; this paper showed a similar phenomenonhappening within the United States.

That land conversion, the scientists concluded, would have released large amounts of carbon dioxide and other greenhouse gases into the air and makes ethanol fuel every bit as bad for the climate as the gasoline it's intended to replace.

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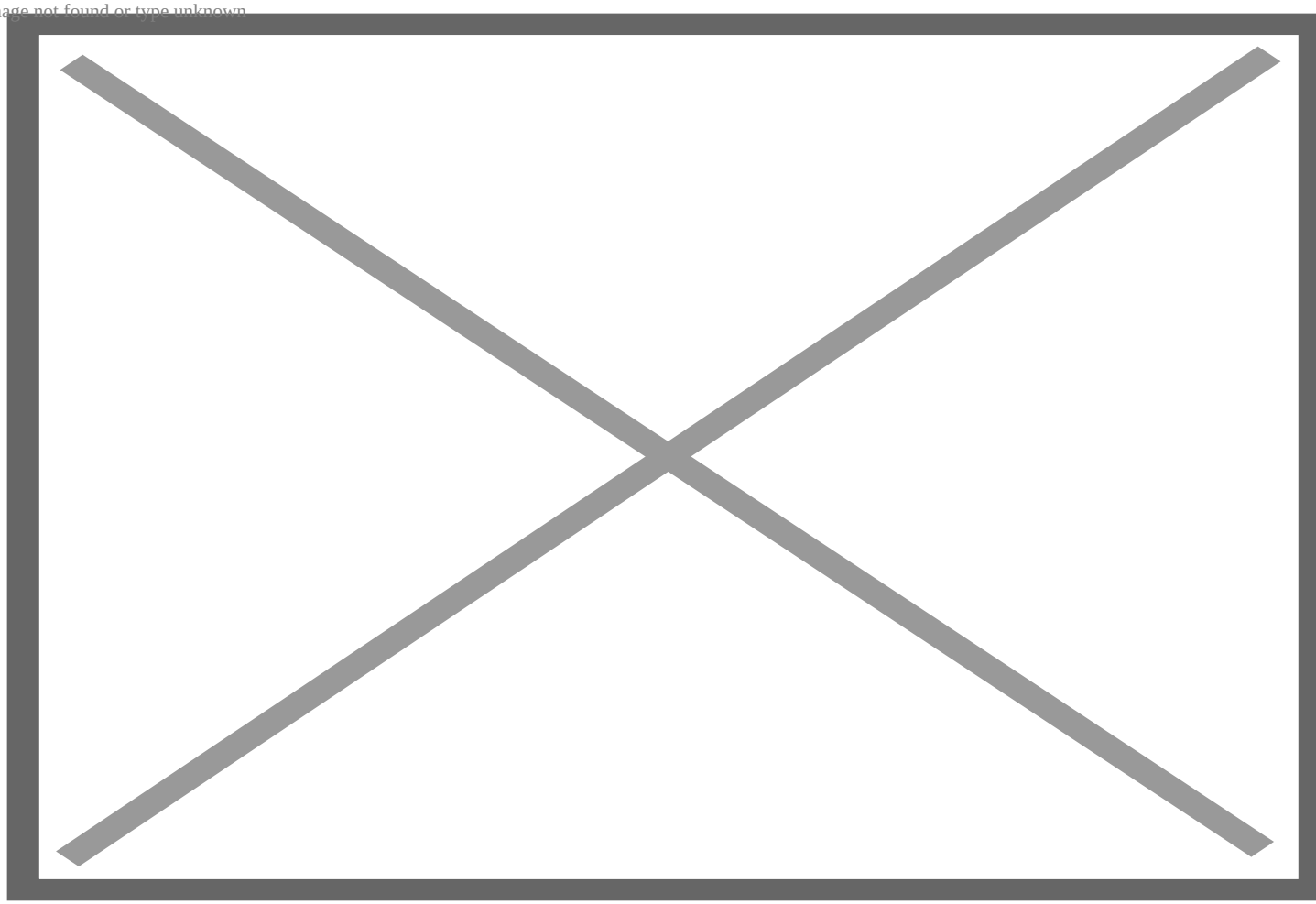

Continuous measurements of carbon dioxide levels at the Mauna Loa Observatory have revealed that humans are contributing to a relentless increase. But these measurements only reveal the portion of emissions that remain in the atmosphere, and not the total emitted by human activities. Credit; Scripps Institution of Oceanography

Farmers and biofuel trade groups lashed out against these findings — and against Lark himself. A biofuel industry association demanded that he and one of his coauthors be blackballed from a government expert review panel on renewable fuels.

The dispute came at a moment when world events laid bare the tradeoffs of biofuels. Less than two weeks after Lark's paper appeared, Russia invaded Ukraine, provoking a spike in prices for both food and fuel — which already had been scarce and expensive because of the pandemic. Biofuel supporters have called for incentives to blend more ethanol into gasoline in order to bring down gasoline prices. Anti-hunger advocates are demanding *less* biofuel production, in order to free up land to grow more food. And natural ecosystems continue to disappear.

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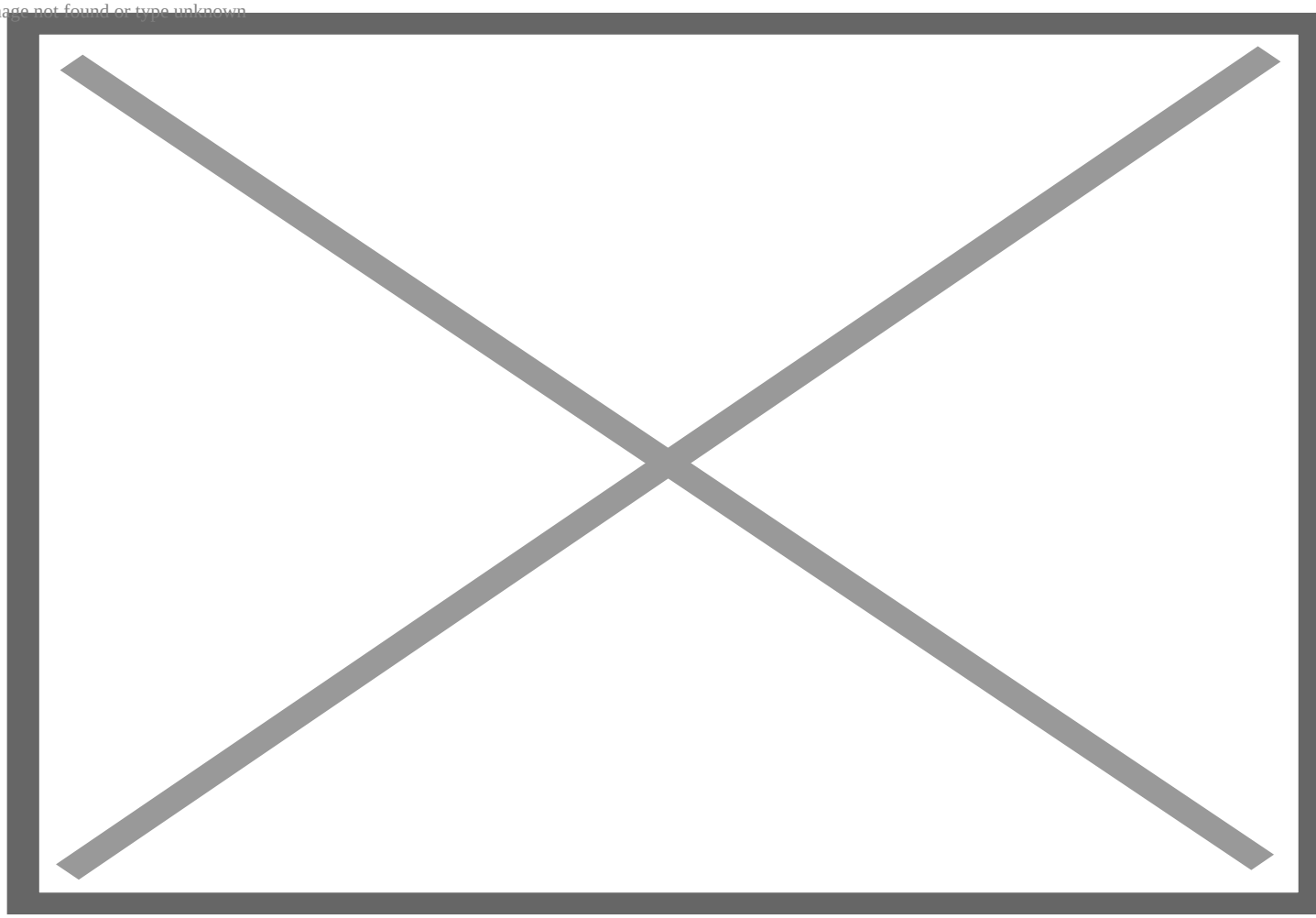

The lesser prairie chicken needs large grassland areas to thrive. Government programs aimed at protecting and expanding such grasslands have helped the species to survive. Credit: Greg Kramos via USFWS and Flickr

As the controversy roils on, a more technical debate among scientists and economists is simmering out of public view: How reliable are the economic models used to evaluate biofuels anyway? Their users defend

them; others disagree. “The results coming out of these models are driven more by assumptions than by actual information,” says Stephanie Searle, an ecologist specializing in biofuel sustainability at the International Council on Clean Transportation (ICCT). She and others say that one influential model, in particular, adopts assumptions that whitewash the fuels’ environmental risks.

Optimism and early warnings

America’s biofuel boom launched in 2005 as Congress passed a law that created the Renewable Fuel Standard (RFS), which required sharp increases in the use of biofuels over the following decade. Congress increased those biofuel targets in 2007. Fuel companies could satisfy the law by mixing more ethanol into gasoline, or by supplementing standard diesel fuel with a version of diesel made from plant oil or animal fat.

The law rested on a foundation of mixed goals. Farmers wanted new markets for their crops. Others hoped that biofuels could be a homegrown, cleaner alternative to foreign oil. Biofuels were supposed to cut greenhouse gas emissions because the carbon contained in them is recycled: It had previously been captured from the air by growing the corn or soybeans to begin with. And even though the factories that turn corn into ethanol require lots of energy and typically burn fossil fuels, it was assumed there would still be a net climate benefit.

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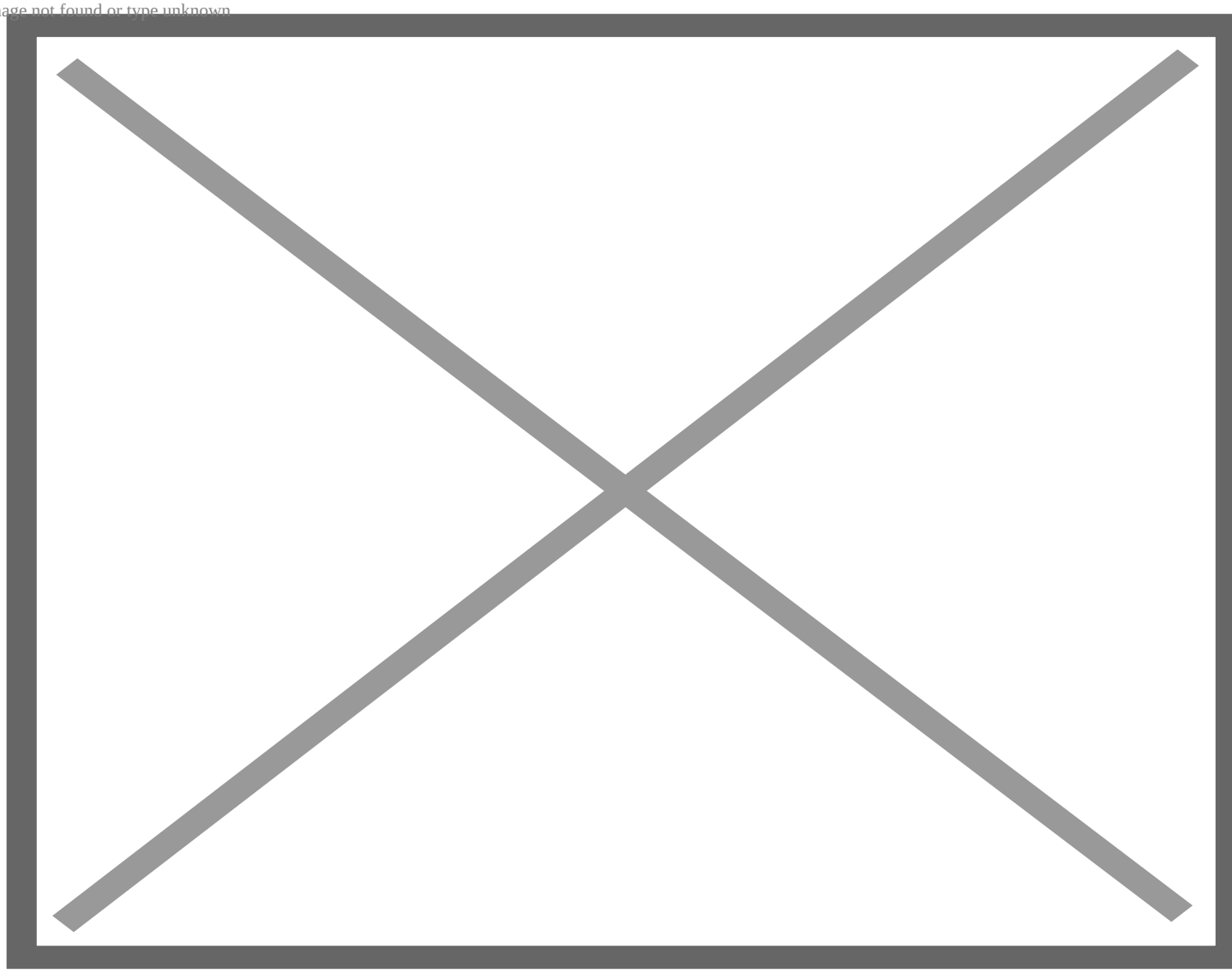

Credit: Thomas Chambers

At the time, “you could easily envision an incredibly optimistic view” of the future, says Sivan Kartha, an environmental scientist with the Stockholm Environment Institute. Bioenergy supporters promised fuels made from plants that were similar to those in native ecosystems, delivering the environmental benefits of grasslands, for instance, while simultaneously replacing fossil fuels.

Yet Kartha could also imagine a darker future, with profit-driven plantations of biofuel crops displacing native forests. He urged caution in an article published in the *Annual Review of Environment and Resources* in 2007. “Bioenergy has the potential to contribute to sustainable development,” he wrote. But “the fulfillment of this potential cannot be presumed.”

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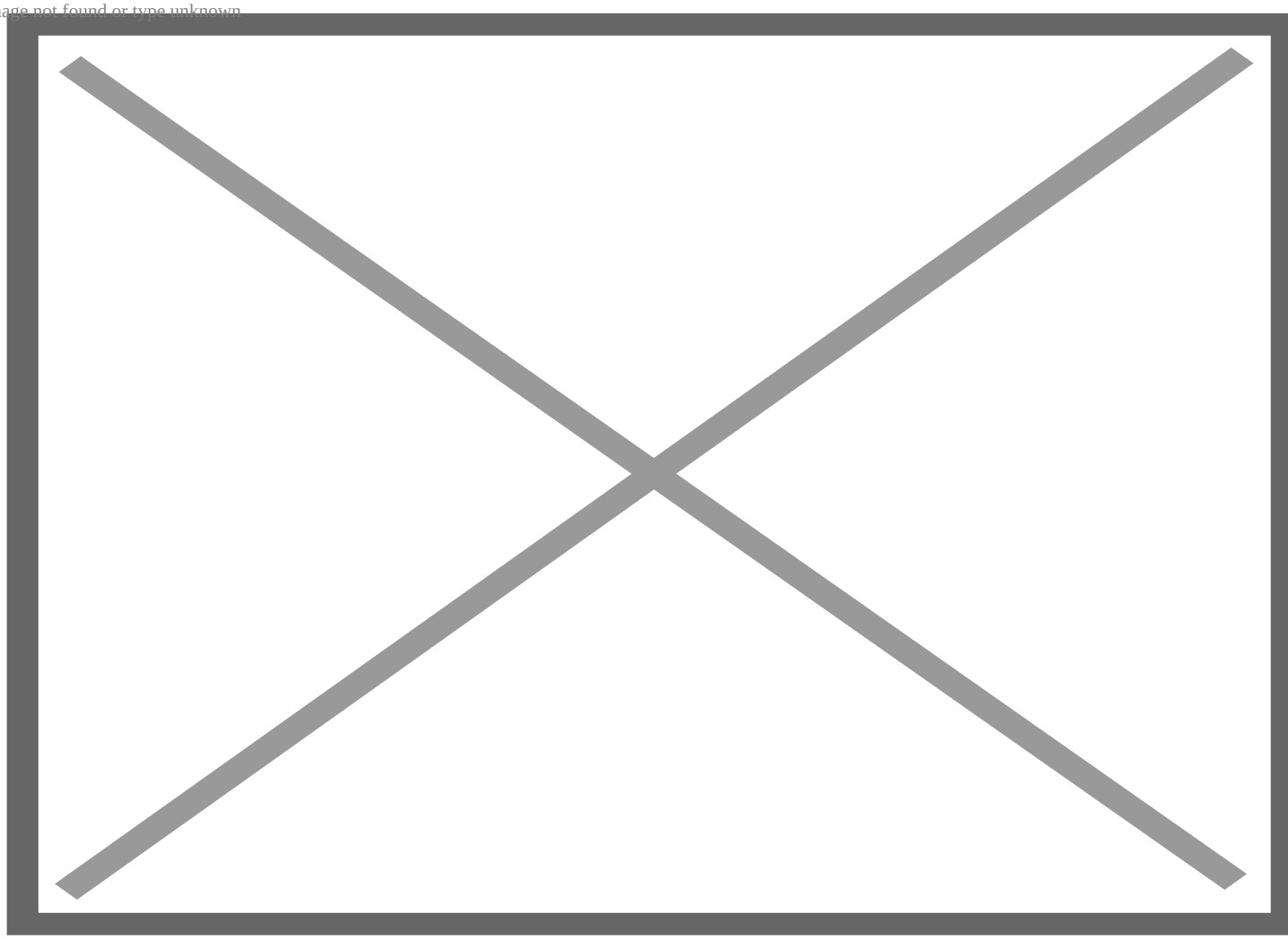

Ethanol production in the United States rose sharply from 2005 to 2012 in order to meet targets set by the Renewable Fuel Standard (RFS). Most ethanol is blended into gasoline, so when consumers abruptly stopped driving in the early stages of the Covid pandemic, ethanol use dropped as well.

As US ethanol production headed toward the RFS-mandated goal of roughly 15 billion gallons a year, scientists grew increasingly worried that the appetite for biofuel, added to rising demand for food, could consume vast amounts of land. “It got us thinking about what the consequences might be, for the climate,” says Jason Hill, an environmental scientist at the University of Minnesota. In 2010, Hill and coauthors wrote in the *Annual Review of Ecology, Evolution, and Systematics* that “the largest ecological impact of biofuel production may well come from … land-use change.”

Scientists have been trying to measure that impact ever since, but it’s surprisingly difficult. New ethanol factories don’t clear land directly. They merely buy corn. Those purchases, however, can drive up corn prices and persuade farmers to expand their fields in pursuit of profits.

And the impact of ethanol production can easily be lost amid many other factors affecting the price of

corn, including weather disasters and demand from cattle feedlots and dairy farmers. “You can’t go out on the landscape and say, ‘This parcel was converted 100 percent due to this policy,’” says Lark.

So, in their search for biofuel’s fingerprints, researchers have turned to computer simulations of the global economy, such as one created by the Global Trade Analysis Project at Purdue University. GTAP-BIO, as it’s called, has been specifically adapted to study biofuels and their effect on land. Some government agencies — notably, the California Air Resources Board — rely on it to calculate the “carbon intensity,” or climate impact, of biofuels.

GTAP-BIO is like a giant spreadsheet of the world economy. It contains data on production and consumption of goods and services across the entire globe, along with assumptions about the mathematical relationships between them — between, for instance, the area of land devoted to growing corn and how it is used.

In this simulated world, researchers can change just one element, such as corn demand from new ethanol factories, and watch the model calculate the cascade of consequences. They can create alternate versions of history, such as one in which the ethanol boom didn’t happen, and see whether farmers still expanded their cornfields. They can also use it to predict what will happen if biofuel production expands in the future.

Over the past decade, refinements of the GTAP-BIO model have delivered increasingly reassuring verdicts. They find that biofuel production induces only a modest amount of land-clearing. When ethanol factories expand, they do bid up the price of corn, but then the world adjusts. Other buyers of corn, such as cattle feedlots, cut back on their purchases. Farmers find ways to boost crop yields, perhaps by investing in better seeds or more effective weed control. This all reduces the need for additional land.

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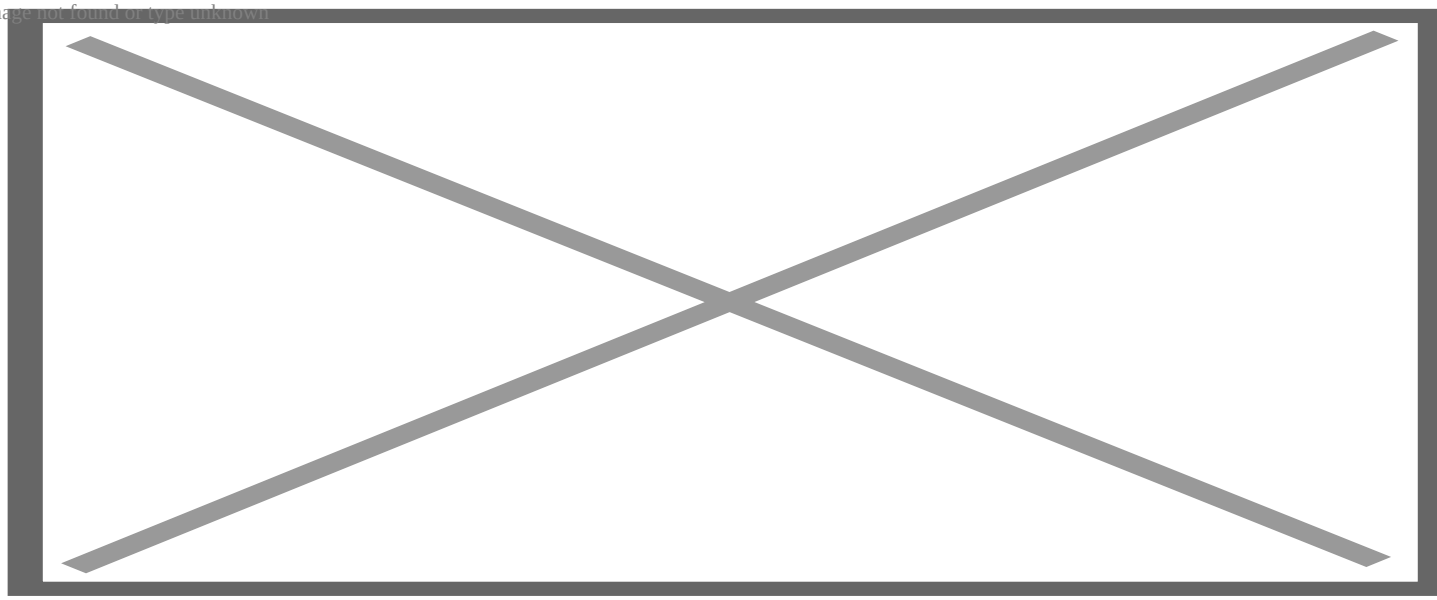

Ethanol factories are giant distilleries. They cook the grain, ferment the starch and collect the resulting ethanol. Credit: Matt Oaks via Alamy

In addition, even when US farmers do expand their cornfields, GTAP-BIO shows them often claiming marginal land called cropland-pasture, so named because farmers use it for either purpose, depending on circumstances or economic conditions. In the model, this land lacks the carbon-rich soil of native prairie, accumulated from many generations of deep-rooted grasses. When you dig it up to plant corn, very little carbon dioxide is released into the air.

Yet several of these assumptions have come in for harsh criticism. Chris Malins, a UK-based mathematician who has worked as a consultant on biofuels for environmental groups and the European Commission, says the GTAP-BIO team's work exhibits a pro-biofuel bias. He says they readily adopt assumptions that produce lower estimates of greenhouse gas emissions from biofuels, while challenging evidence that would move its calculations in the opposite direction. As a result, GTAP-BIO has made ethanol look better and better over the past decade, Malins says.

A prime example, he says, is GTAP-BIO's conclusion that cropland-pasture releases relatively little carbon when it's converted to cornfields. One version of the model, in fact, calculates that converting this land actually tends to capture carbon dioxide from the atmosphere, rather than releasing more of it. In a study published in 2020, Malins and two coauthors wrote that this result rests on a "bizarre" assumption that the land had already been used to grow crops for several decades before switching to corn for ethanol. In reality, Malins and other scientists say, much of this land previously had been covered in grasses for many years and had relatively carbon-rich soil.

GTAP-BIO's critics also doubt that farmers actually boost their yields of corn in response to higher prices. Yields have indeed increased steadily, researchers say, but not because prices went up. They've increased during periods of low prices and high prices alike.

Richard Plevin, a biofuel expert now retired from the University of California, Berkeley, says that GTAP-BIO also ignores the reality of land-grabbing and deforestation in countries like Brazil. The model classifies large areas of natural forest as "inaccessible" — and assumes that this land, by definition, cannot be converted into cropland. This assumption also results in low estimates of deforestation and carbon emissions.

Farzad Taheripour, an agricultural economist at Purdue and a key member of the GTAP-BIO team, rejects these criticisms out of hand. The assumptions in the model, he says, are based on the best evidence that the team can find, and nobody is trying to make biofuels look more climate-friendly than they really are. "All the changes," he says, "are based on facts."

Taheripour adds that history validates the model: Thanks to steady increases in crop yields, farmers have been able to satisfy demand for both food and fuel without destroying natural ecosystems, at least within the United States. "That's the lesson of the past 15 years," he says. "We produced more food, we produced more biodiesel, more ethanol. We eat more meat. Where are those coming from? From yield improvement. The only significant land conversion in the United States has been conversion of unused cropland to cropland. So, then, why do I have to be worried?"

There's little dispute that in the US, the ethanol boom has mainly affected land that was farmed at some

time in the past, and that higher-yielding crops have helped to meet the growing demand for fuel. But that’s not the end of the argument. There’s another question, one that Lark and his colleagues also explored: If ethanol factories had not claimed the expanding harvest of corn, what other benefits might that land have delivered?

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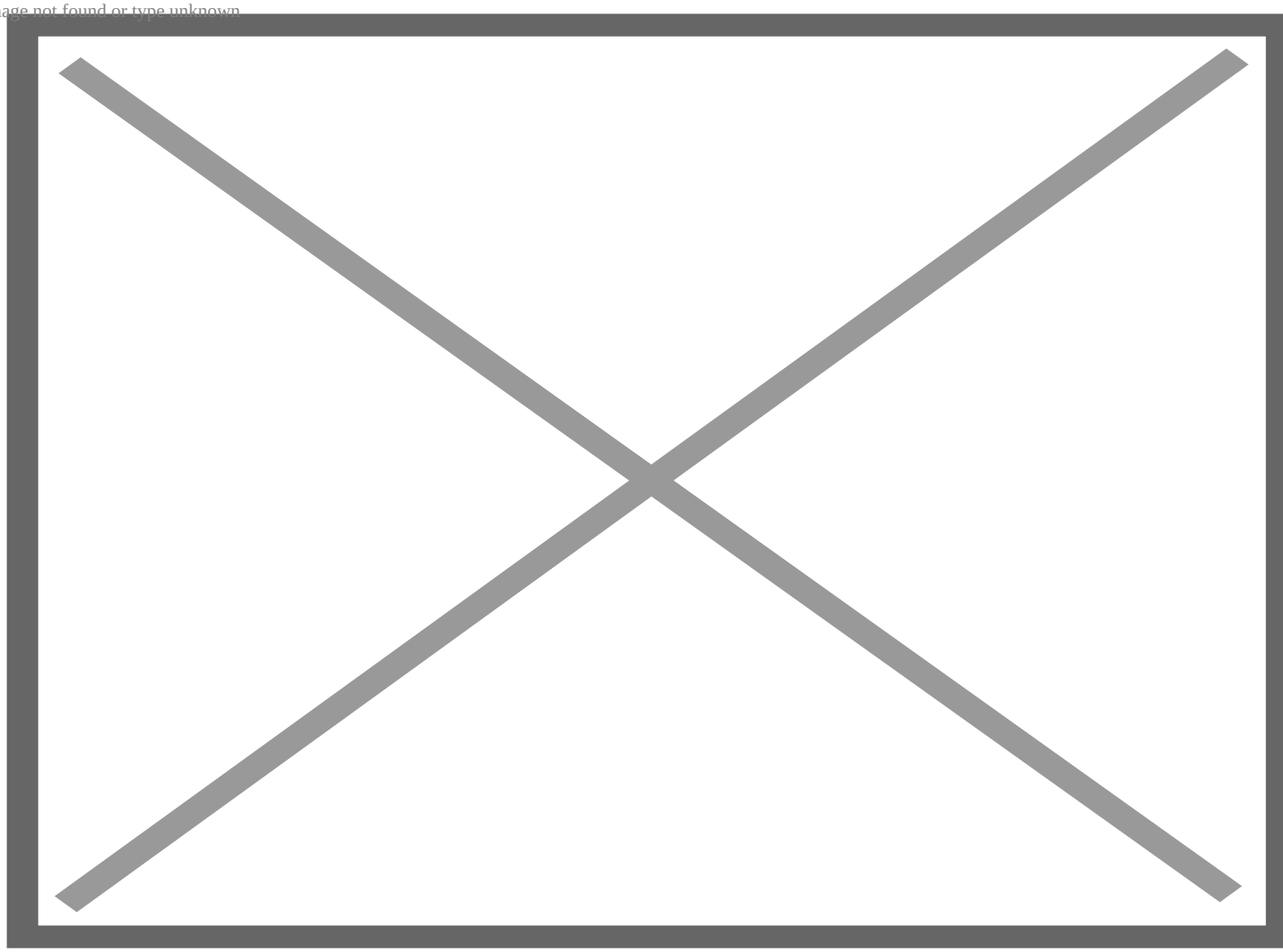

This map shows where grasslands were converted to cropland (in red) or the reverse (in blue) during the US ethanol boom. Grassland conversion was most common in North and South Dakota, southern Iowa and western Kentucky.
Credit: T.J. Lark et. al. via Nature Communications 2020

The changing landscape

In his office at the University of Wisconsin-Madison’s Center for Sustainability and the Global Environment, Lark brings up images of agricultural land on his computer screen and zooms in on a small river winding through several square kilometers of grassland in South Dakota.

This land could have been a wheat field in 1932, when the footprint of American agriculture reached its peak, with 375 million acres planted in crops. But at some point, its owners let the grass grow again, perhaps to graze cattle.

They weren't alone. Following the epic disasters of the Dust Bowl and Great Depression, areas of cropland in the US shrank by 22 percent. Cropland almost returned to its all-time peak in 1981, then fell again by 13 percent, in fits and starts, for two-and-a-half decades — until 2007, when Congress approved the final version of the Renewable Fuel Standard. At that point, the area of cropland stabilized.

The photo Lark is examining was taken about a decade ago. With the aid of Google Earth, he does a bit of time travel, scrolling forward through images captured in later years. As he scrolls, much of the grassland disappears, replaced by fields of corn or soybeans. "It looks like, here, 2012, still in grass; 2014, pretty clearly eaten up into the surrounding fields," he says.

South Dakota was a hot spot of land conversion during those years, but people noticed similar trends across other parts of the Midwest, and they wondered why. "We always got asked, 'What portion of this is due to biofuels?'" Lark says. "It's a really tough question. We never really had a good answer." The National Wildlife Federation gave him a grant to find that answer.

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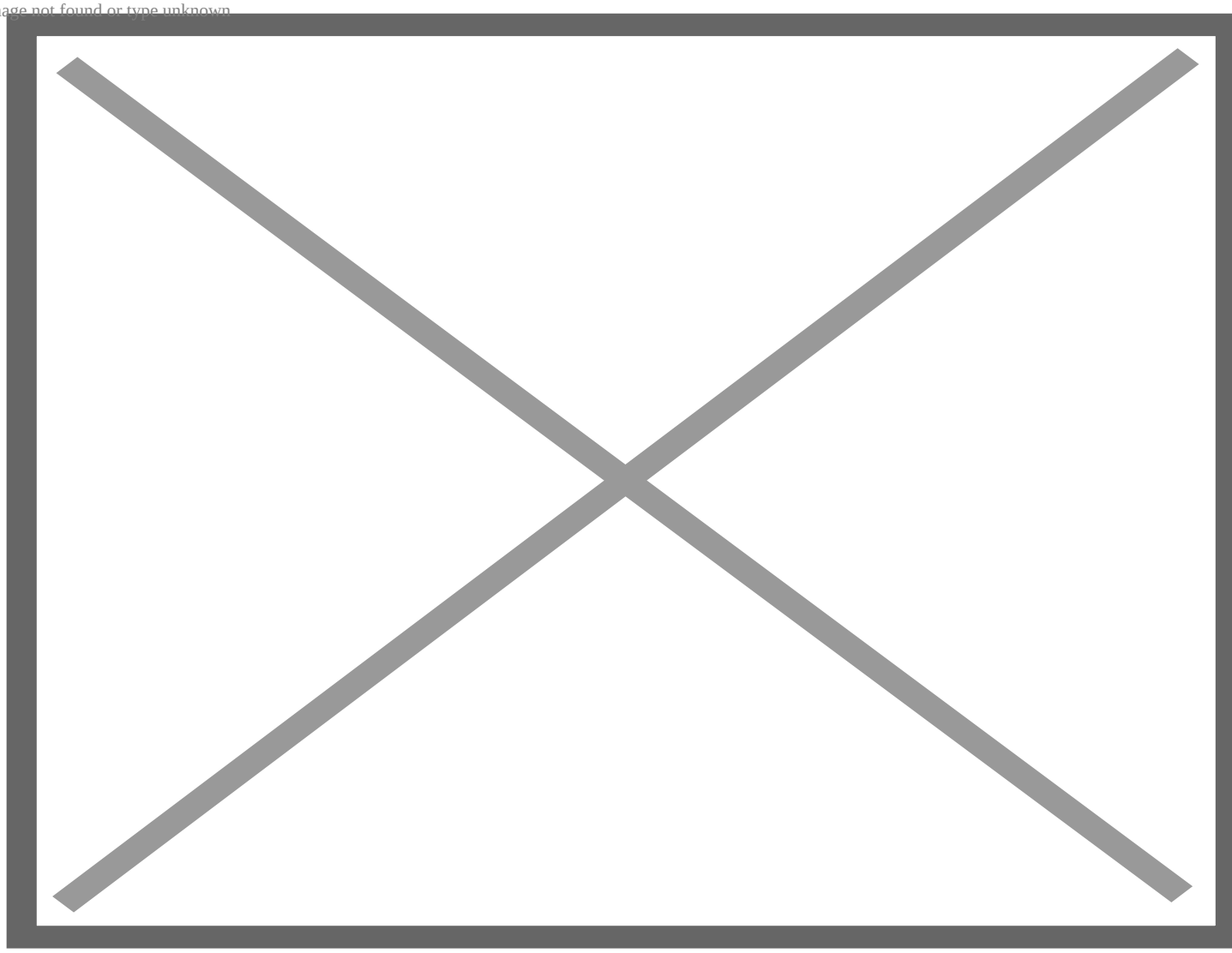

Tyler Lark, a geographer and land systems scientist with the University of Wisconsin-Madison, and his daughter, Vera, feed their backyard chickens, Maple and Zoey. Credit: Tyler Lark

Lark and his team of economists and soil experts sidestepped global economic models with their complicated assumptions. They started with what Lark knew from his previous work — actual shifts in land use during the years when ethanol production was expanding. They then used a simple model of supply and demand for major crops to describe what might have happened if the Renewable Fuel Standard had never become law.

Part of their answer was unsurprising. Without the ethanol boom, the pre-2007 trend in land use would have continued. More land — 5 million acres — would have remained in grass between 2008 and 2016, rather than being converted to grow crops.

The attention-grabbing part was their estimate of the change in greenhouse gas emissions for the path that was actually taken. In contrast to GTAP-BIO, they found that many of the newly expanded cornfields

contained soil rich in carbon because it had been grassland for a decade or more. Tilling and fertilizing that additional land released a burst of carbon dioxide and nitrous oxide — so much, in fact, that ethanol produced from that corn was just as bad for the climate as gasoline, and likely more than 20 percent worse.

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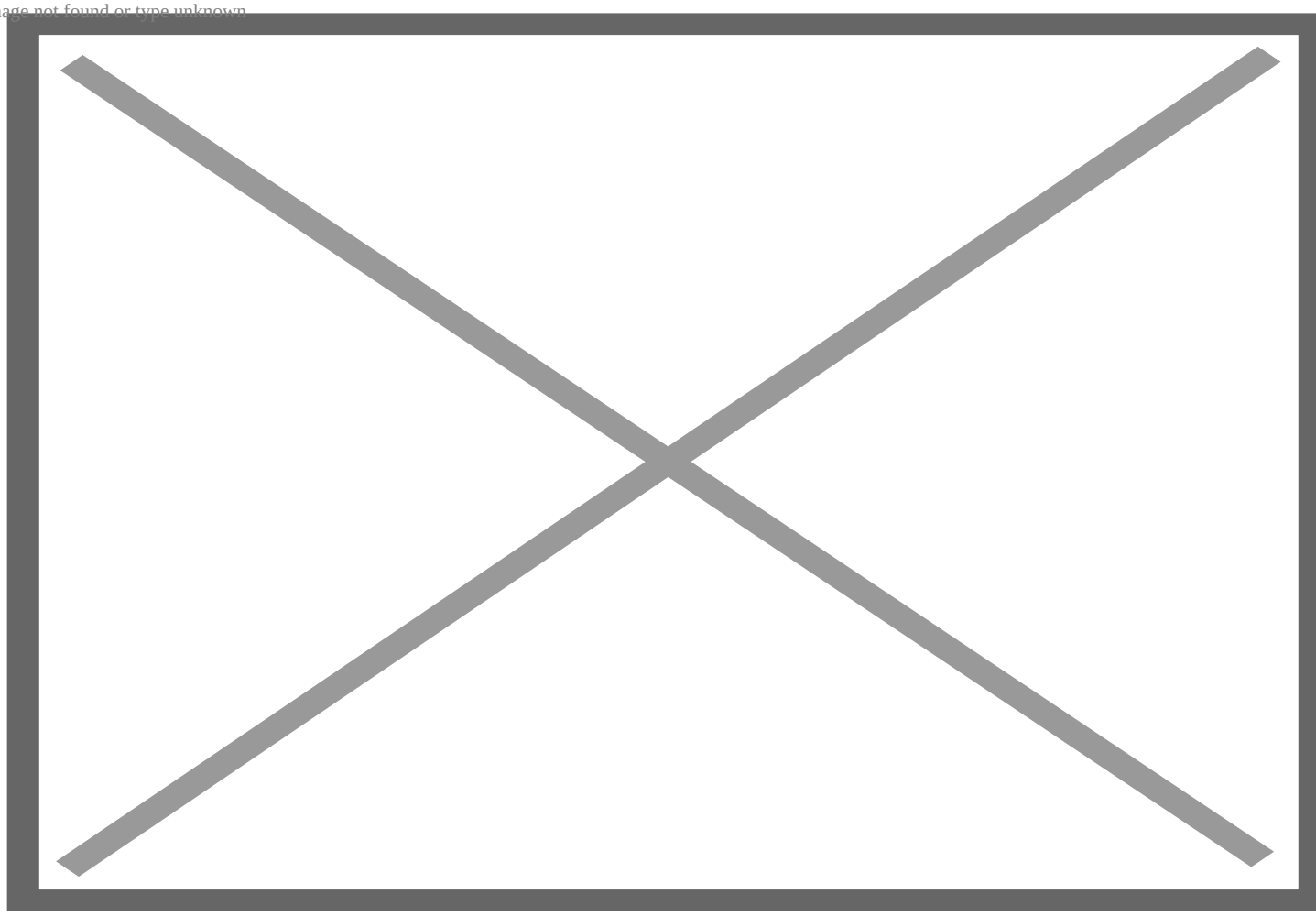

Tilling and fertilizing can lead to pollution, including nitrous oxide, a potent greenhouse gas.

When the paper appeared in the *Proceedings of the National Academy of Sciences*, the decade-old battle over biofuels erupted anew. Taheripour, joined by other scientists, posted a critique of the paper online, slamming its methodology and arguing that it systematically overestimated carbon emissions from land conversion. Industry groups cited that criticism in their own attacks. The Renewable Fuels Association called Lark's study a "hit piece" on its industry and asked the Environmental Protection Agency to exclude Lark from a review panel on biofuels that the agency was organizing because his work "suffered from known flaws and inaccuracies."

When Lark and his coauthors responded, defending their methods and conclusions, Taheripour's group rebutted with an even harsher 35-page critique.

Much of the dispute involves technical issues involved in calculating carbon emissions from land

conversion. But Lark and Taheripour also have deeper differences, rooted in different priorities for the country's land.

Taheripour warns of a return to the years before the biofuel boom, when US farmers were plagued by a glut of grain, driving down prices. "There was no market for corn," he says. "We started to produce biofuels to not throw away our crops into the ocean."

If ethanol production plants weren't there to buy corn, he says, farmers would have to idle some of their land — and idle land, he says, "doesn't have any value."

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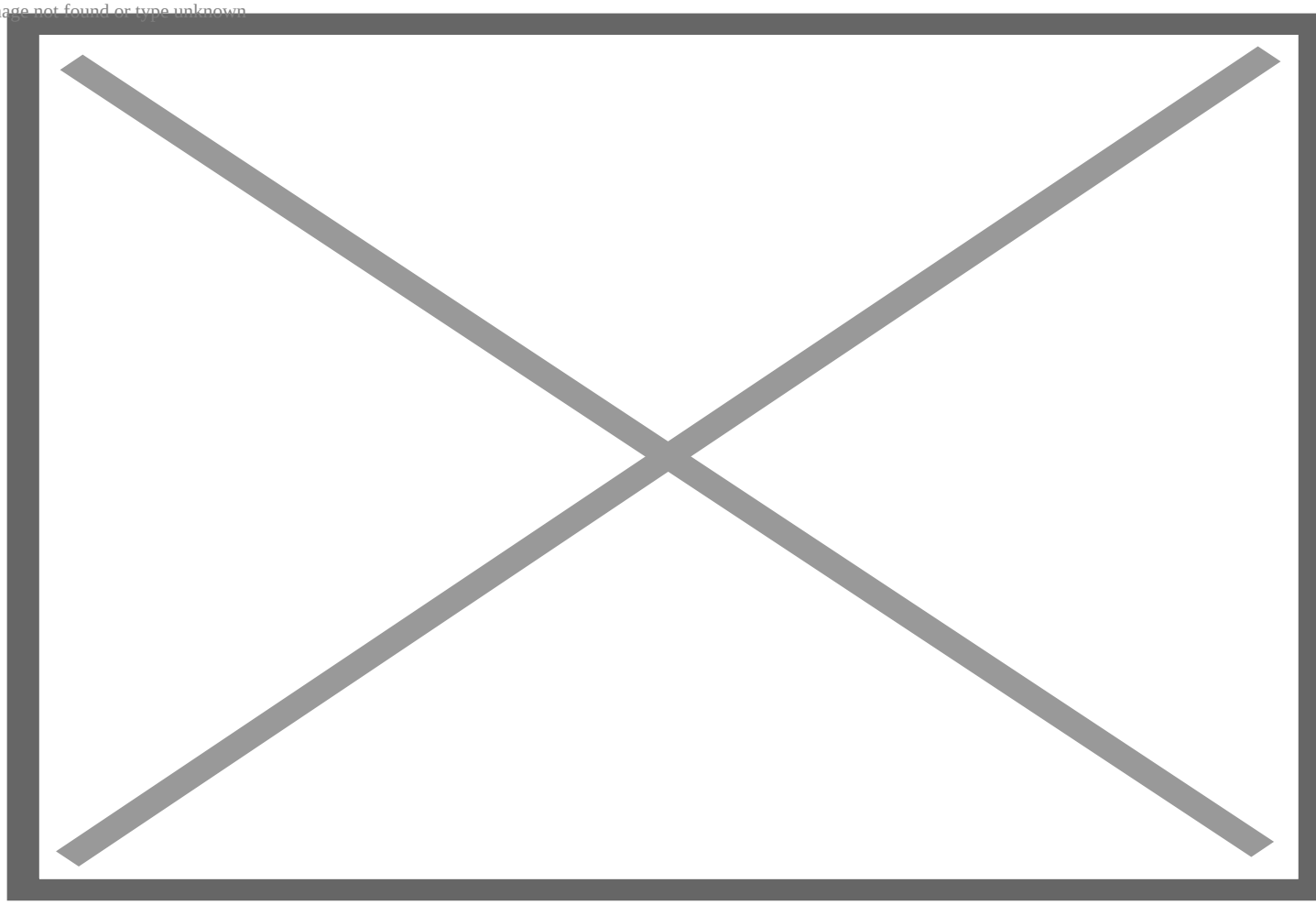

Corn is unloaded at an ethanol plant in Chatham, Ontario. Credit: Mark Bunch via Reuters

But the counterfactual scenario in Lark's paper — the path not taken — implicitly makes a different point. If land is freed from the need to supply ethanol plants, it can deliver vital environmental benefits. Grasslands can capture carbon from the atmosphere and store it in the soil, a kind of natural climate solution that also cleans up waterways and provides habitat for birds, pollinators and other wildlife. Such solutions are a crucial part of many scenarios for reaching net zero emissions goals.

The hard part — and Lark and Taheripour agree on this point — is figuring out ways to measure those

environmental benefits and pay landowners for them, just as they get paid for growing corn. To some extent, the US Department of Agriculture does this already, with programs that pay farmers to preserve areas of grassland or forest. Such initiatives are set to expand; the Inflation Reduction Act, which Congress passed in August, gives them an extra $18 billion in funding.

A grass that’s greener

There is one version of biofuel that both Lark and Taheripour would welcome: energy from perennial vegetation such as native prairie grasses. The grass could be harvested, leaving the roots to grow undisturbed, building up carbon-rich organic matter in the soil and avoiding most of the environmental damage that results from converting land into cornfields. That harvested cellulosic biomass could be fermented to produce ethanol or simply burned in power plants. “You’d have all these environmental benefits of reduced runoff, improved water quality, providing some wildlife habitat, and still be able to harvest that and use it for bioenergy,” says Lark.

Biofuel enthusiasts have dreamed of such fuels for decades, and research on them continues, including at the Great Lakes Bioenergy Research Center, right down the street from Lark’s office. So far, though, they haven’t been commercially successful. Unlike starchy kernels of corn, stalks of grass have to go through additional stages of processing before ethanol-producing microbes can feed on them, and that’s expensive.

Instead, enthusiasm has shifted to another version of biofuel, called renewable diesel. It’s made in oil refineries that have been configured to process soybean or corn oil, or animal fats like tallow from beef slaughterhouses.

But unfortunately, renewable diesel doesn’t end the competition for land. If anything, it intensifies that conflict, because renewable diesel increasingly is manufactured directly from vegetable oils that might otherwise nourish people. Its use currently is rising more steeply than that of ethanol.

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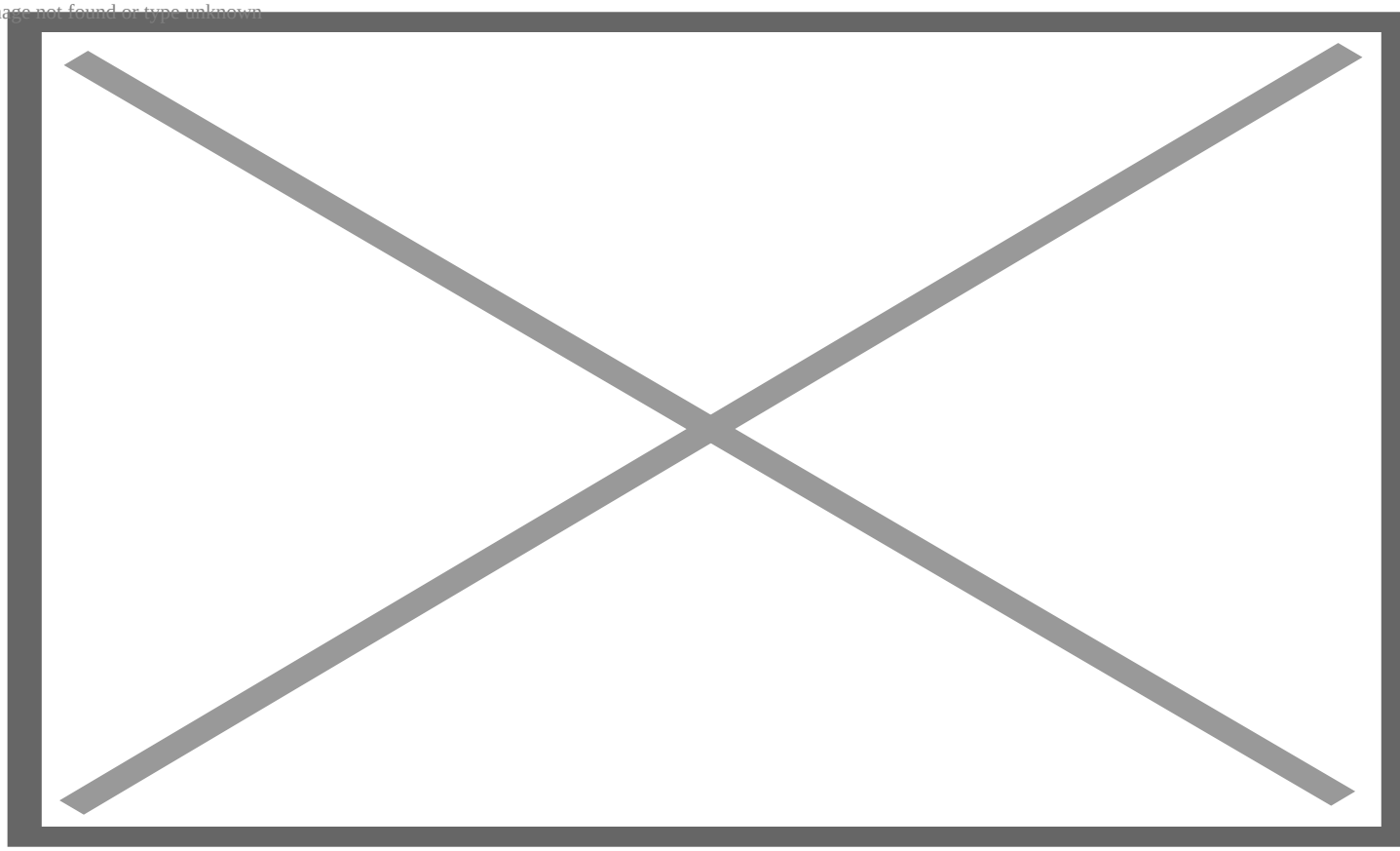

Many companies, including traditional oil refiners, have announced plans to expand production of renewable diesel. This could increase production up to six-fold, but experts expect some plans to be canceled.

Production of renewable diesel is still relatively small, but it's growing fast thanks to financial incentives from California's Low Carbon Fuel Standard, the centerpiece of the state's effort to cut greenhouse emissions from transportation.

California relies on Purdue University's GTAP-BIO model to calculate the greenhouse gas emission scores for every type of biofuel produced at individual factories. The model typically gives good scores to renewable diesel — which means that companies earn lots of lucrative carbon credits for making it.

Stephanie Searle, from the ICCT, says those scores are far too favorable. The environmental impact of renewable diesel, she says, will be felt as far away as the forests of Indonesia. Renewable diesel refineries are bidding up the price of soybean oil, she says, and it's pushing traditional users of that oil to buy palm oil instead.

This boost in demand for palm oil, in turn, could threaten Indonesia's tropical forests — including areas of carbon-rich peat soils that release massive amounts of carbon dioxide when cultivated.

Production capacity of renewable diesel doubled in the past year. Together with other, similar, renewable

biofuels, it has surpassed 2 billion gallons a year. It, and an earlier version of biomass-based diesel called biodiesel, now account for nearly a third of all diesel fuel sold in California. Canada and Oregon are implementing similar laws that will also boost demand.

Even more alarming, critics say, is that — unlike the Renewable Fuel Standard, which merely mandated a minimum amount of biofuel use — California's incentives could drive an unchecked upward spiral in biofuel production. "It unintentionally supports this massive expansion of use of vegetable oils for renewable diesel," Searle says.

This refinery in Paramount, California, owned by World Energy, once handled crude oil. It now converts beef tallow and plant-derived oils into renewable diesel. Credit: Dan Charles

It's this possibility — that a blind quest for alternatives to fossil fuels could drive explosive growth in demand for biofuels — that worries Kartha, of the Stockholm Environment Institute. "Our appetite for energy, as we know, is pretty insatiable," he says. Switching to electric cars will cut demand for ethanol, but there's a new push to deploy biofuels in places where batteries struggle to do the job, such as aircraft, ships and long-haul trucks.

According to Kartha, the world's croplands, which have claimed vast ecosystems, cover less than half an

acre per person on the planet. Producing enough biofuel to power one typical passenger car, meanwhile, requires more than 1.2 acres. (Photovoltaic solar arrays produce many times more usable energy per acre of land than biofuels, and can also be located in dry areas that can't grow food.)

It's clear, Kartha says, that relying on crops to fuel the world's cars would massively multiply the demand for fertile land — with potentially disastrous consequences for those who depend on that land to survive.

It is also becoming clearer to the scientists who've been debating biofuels that they'll never resolve their differences on the exact effects of biofuel production on greenhouse emissions. "It's a very polarized question," says Madhu Khanna, an agricultural economist at the University of Illinois at Urbana-Champaign who coauthored the critiques of Lark's paper. For some, she says, concerns will remain, "no matter what the evidence is."

Searle, for her part, says attempts to fine-tune economic models and calculate the impacts of biofuels are "an exercise in futility" and she thinks that governments should stop relying so heavily on models to calculate economic incentives for biofuels. Instead, they should limit production to a level that won't provoke more destructive land-clearing. Searle and her colleagues are calling on California to put a cap on the amount of plant-based oil that can be legally processed into fuel. "Maybe it could be something like current usage, increasing very slightly over time," she says. "Just find some way to limit the explosive growth."

Dan Charles is a freelance reporter and audio producer in Washington, DC. He writes about farming, the environment and climate change.

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