gevo®
FUELING THE FUTURE

FOOD AND FUELS: STRIKING THE RIGHT BALANCE

Advanced renewable fuels offer a pathway to sustainable energy sources that also contribute to a healthier, readily available food supply.

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FOOD AND FUELS

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Introduction

Life often seems to be full of trade-offs. Sometimes, you can *only* have A or B, but not both at the same time. Decide, and live with your decision. After all, you can't have your cake and eat it, too. Or can you?

All of us, however, have figured out how to *optimize*, and not just *compromise*, when faced with seemingly conflicting options—like when the washing machine needs repair and the kids need new shoes for school—we figure out how to send them to school with shoes that fit and clean clothes, too. Creativity and innovation can also help us find win-win solutions to the suggestion that we can only have food or sustainable biofuels, but not both.

At Gevo, we have responded to the pessimism of false choices by turning the challenges into opportunities. It's a core tenet of our business.

First, we asked the question, *Why not?* Working within the framework of science and nature in the form of industrial chemistry and synthetic biology, we are disrupting the conventional thinking and using the intertwined systems of nature and commerce more intelligently.

We invented the process to make renewable fuels that use carbon naturally captured from the atmosphere, rather than dug up or pumped out of the ground. In doing so, we got off the one-way fossil energy path to gain an increased range of movement. The fossil carbon from petroleum, natural gas, and coal is on a linear path—removed from the ground, refined (using more fossil energy), combusted in an engine or boiler, and released to the atmosphere. It's a non-sustainable, non-renewable life cycle, with opportunity for improvements in efficiency, but not for fundamental transformation.

Gevo thinks about the opportunities differently. We make isobutanol or ethanol, both are alcohols, from No. 2 yellow dent corn, an industrial crop used historically to feed livestock, but that has never been eaten directly by people. We use the carbon in the carbohydrates from that corn, which grows by collecting carbon dioxide from the atmosphere through photosynthesis to make these alcohols,which we then use to build combustible fuel molecules. These fuels work exactly the same way their petroleum analogs do—in fact they're fungible—in the same engines and boilers, but they contain carbon recently drawn from the atmosphere, not from the ground. Our fuels do not add carbon to the atmosphere as a result of that short cycle of corn growth and fuels production and use.

People are legitimately concerned today about the environmental costs of travel, and of everything humans do. With petroleum jet fuel, airplane or other transportation emissions are all fossil carbon that hasn't been in the atmosphere for millions of years, an atmosphere that today has been loaded with too much carbon. Gevo's sustainable aviation fuel produces that same *amount* of carbon dioxide as fossil fuel as a result of jet engine combustion, but the carbon from Gevo fuels was in the atmosphere very recently—within the past few years at most. It's recycling atmospheric carbon, not a new addition of very old carbon. And this climate-friendly, win-win approach can be taken with renewable gasoline and renewable diesel as well. That's optimizing, not compromising!

Another perceived trade-off that concerns many people is the use

EVERY KERNEL OF CORN CARRIES ENERGY AS WELL AS MUCH-NEEDED PROTEIN THAT CAN FEED THE WORLD.

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of farmland to produce fuel. After all, the thinking goes, we need to feed ourselves as well as our machines, and there's only so much farmland. An extension of this argument is that using feed corn for fuel could increase the price of food. Gevo's approach is to optimize the use of corn, not compromise on its uses. Nutritionists looking at the problem of world hunger tell us that protein is the key to a rich food supply. We make isobutanol from corn, but only from the starch of the corn. The protein contained in each kernel is captured in our processes, and used to make a high-protein animal feed. It's the wrong paradigm to think that corn is grown to make fuels, it's not. It's grown for its protein content. Making fuels from corn wouldn't even make economic sense if the protein wasn't valuable for the food chain. The economical thing to do is sell the protein (that usually has more value per ton than the corn in the first place) and use the carbohydrates for something useful that solves a problem—feedstocks for transportation fuels.

For Gevo, protein is not treated merely as a byproduct of isobutanol or ethanol production. At Gevo, protein is a co-product. For every gallon of isobutanol or ethanol we produce, we make several pounds of high-protein animal feed. Gevo will continue producing this animal feed because it's the right thing to do, but also because it makes economic sense to have another product to sell.

Gevo makes fuel and animal feed, all from the same acre of farmland. That's optimizing, not compromising—the best of both worlds.

Background

Part I: Making Fuel a New Way

Gevo takes in inedible No. 2 yellow dent corn from farms in the area of our development facility in Luverne, Minnesota. Just as we expect when our production facilities come online, many farmers deliver their corn by tractor along country roads. No long-haul freight transit is necessary or involved. Scaling production to reduce transport costs is another part of Gevo's design to minimize unnecessary greenhouse gas emissions, and comes with the added benefits of more localized economic development.

The Gevo developoment facility has been fitted with the equipment to make next-generation biofuels. We make ethanol and isobutanol, or as we sometimes refer to it, "IBA." IBA is useful as an oxygenate blendstock for gasoline, much the same way ethanol is used—and both are excellent building blocks for other products.

Thanks to innovation and a refusal to compromise when an optimized solution is possible, the fuels produced by Gevo and improved with Gevo additives will be able to power transportation and

THESE STALKS CAPTURE CARBON FROM THE ATMOSPHERE AS THEY GROW.

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fulfill energy needs around the world, without compromising superior environmental performance. Each gallon of Gevo biofuel that enters the market, whether it's sustainable aviation fuel (SAF), premium renewable gasoline, or renewable diesel, replaces a gallon of fossil fuel that would otherwise be burned in that jet, or city bus, or car, or boat, or lawn mower. Gevo's renewable fuels are:

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Isobutanol (IBA): It is a starting point for Gevo fuels, and it's a product in its own right. Isobutanol is also a blendstock oxygenate for gasoline and works well in marine and small engines.

Sustainable Aviation Fuel (SAF): While there are five different pathways to creating renewable jet fuel, Gevo uses Alcohol-to-Jet synthesized paraffinic kerosene or ATJ-SPK methods to create the necessary 12-carbon chain from its ethanol and isobutanol.

Isooctane: Isooctane is a gasoline replacement that is already in use, sold as packaged fuels in Europe, and on professional auto-racing circuits. Gevo uses its alcohols as a base to create the eight-carbon chain found in the fuel cells of the fastest racecars.

Renewable Gasoline: Gevo isooctane plus renewable alcohol (like IBA or ethanol), and other components make a whole gallon of gasoline. Gevo expects to producethe components at scale, and, as costs fall, this could be the fuel of the future for personal transportation.

Renewable Biodiesel: Diesel drives much of the freight hauling and transportation around the world, and to have a renewable replacement would reduce a large part of the world's transportation carbon footprint and GHG emissions. Gevo has developed a way to make biodiesel from alcohols.

Ethanol: It's the original fermented fuel blendstock, made from corn or lignocellulosic feedstock.

How Gevo Makes the Most of the Life-Cycle Assessment

GHG emissions for biofuels are most commonly evaluated through a life-cycle assessment, which calculates the amount of greenhouse gases that are released per unit of fuel, including emissions and carbon sequestration. Emissions reductions are higher for advanced biofuels. (Environmental Energy and Study Institute, "Biofuels Vs. Gasoline: The Emissions Gap Is Widening," September 2016). Gevo's product line focuses on decarbonization of the entire process to give each of its biofuels, chemicals, and co-products the lowest carbon life-cycle assessment (LCA) possible—to optimize the benefits of these fuels. The LCA is widely considered to be the best yardstick of true carbon intensity in biofuels and chemicals produced to replace fossil fuels, because this metric takes into account the full range of carbon emissions and sequestration from all steps of the process.

Burning biofuels releases carbon into the atmosphere. Every gallon of Gevo biofuel coming from sustainably grown corn helps sequester more carbon in the soil, and also helps to leave the fossil carbon in petroleum, methane gas, and coal locked in the earth's crust.

Carbon dioxide in the atmosphere is consumed in corn fields as millions and millions of corn stalks grow from seed to more than six feet tall, storing energy in stalk and root, leaves, and most importantly, the kernels of corn. The process is repeated each and every year a crop is grown.

Part II: The Co-Products of Biofuel Production

Biofuel production at Gevo does not use the entire kernel of feed corn that is the primary feedstock to make isobutanol or ethanol. The process uses the starch, and that leaves Gevo with plenty of protein from the corn. Protein is critical to the food supply: Meat is the source for 18 percent of the world's protein consumption, and meat consumption has grown by 60 percent between 1990 and 2009 (Henchion M., McCarthy M., Resconi V.C., Troy D., "Meat Consumption: Trends and Quality Matters," Meat Sci. November 2014).

The protein the company captures is turned into animal feed. On a weight basis, Gevo has demonstrated its process produces more animal feed than transportation fuels. Because this feed creates an additional revenue stream for the company, it helps to offset the cost of producing renewable fuels. In addition to improving product economics, a co-product approach allows Gevo to be more precise in carbon-emissions accounting. We pay attention to the quality of our animal feed and price it to sell locally, so we don't need to address high shipping costs and the carbon intensity that comes from shipping. Gevo expects to own ethanol and isobutanol production facilities in the future, creating more local economic and feed-production benefits.

High-protein animal feed is better for livestock and can result in healthier livestock, while lowering the GHG emissions from cows. When cows eat feed with high concentrations of starch or corn sugars, their stomachs tend to produce more methane emissions. By stripping the carbohydrates, which have no nutritional value, from the

protein, it makes a better animal feed product, and lowers emissions attributed to dairy and beef production.

Part III: More Energy an Better Soil

Farmers who keep livestock as a complement to growing corn have a natural source of inexpensive fertilizer from manure, without trucking in synthetic fertilizers. Another aspect of using manure as fertilizer is that it keeps the minerals and nutrients inside the production and use cycles on the farm. As the feed passes through the livestock, the nutrients are returned to the farmland where they can aid the soil quality and support crop growth in future years.

The life-cycle assessment is widely considered to be the best yardstick of true carbon intensity in biofuels and chemicals produced to replace fossil fuels, because this metric takes into account the full range of carbon emissions and sequestration from all steps of the process.

Gevo is also developing a system to work with farmers to install manure digesters on their farms. Manure in these enclosed digesters, which use bacteria to break down the manure, produces methane—biogas—which is then captured and used for energy production. Locally produced biogas can offset even more of the fossil energy use at the farm and at Gevo plants.

The production and use of biogas as part of the cycle of producing renewable biofuel and high-protein animal feed augments the life-cycle assessment and simultaneously reduces the carbon intensity of all products involved.

Most farmers are smart. They have to be or they would be out of business. The land is their asset, their means of making money. Over the last decades farming has evolved. Farmers use precision agriculture with advanced GPS and mapping techniques to apply the fertilizer or other chemicals that are needed only in the precise amounts and locations in the field. They have learned that by leaving the stems, leaves, and stalks on the field, they recycle nutrients back into the soil, meaning they have to buy less fertilizer the following year to condition the soil. They have learned that by using low-till or no-till cultivation techniques, that the soil builds up, and helps to keep nutrients in place. They have installed ground-water protection to reduce runoff.

When thinking about farming, the building up of soil, we realize that the carbon comes from the atmosphere. It is fixed. We hear oil companies talking about carbon sequestration to help solve GHGs. In the meantime, farmers are quietly doing it, sequestering carbon. They take the carbon out of the atmosphere and put it in the ground. Agriculture has enormous potential to capture even more carbon, leveraging the system to produce food.

Issues Surrounding Food and Fuels

Issue: *As demand for biofuels grows, will farmers have to convert native prairie grasslands to increase the supply?*

No. There is enough land. The USDA reports that farmland has actually decreased in U.S. in the last 100 years, while production has increased dramatically.

On a worldwide basis, we find that the amount of agricultural land is not changing much, but that productivity is. This trend is expected to continue as more countries adopt modern agricultural practices.

When considering agricultural crops, it's important to remember that most are grown for their protein for the food chain. In some regions of the world, there could be more acres used to produce protein. By selling the carbohydrates that are produced with the protein, it actually makes the protein less expensive. But if there is expansion of farmland, it is always food first.

Because it doesn't make sense to grow crops only for their carbohydrate content, with the exception of sugar beets and sugar cane, there is a practical market limit to the expansion of crops.

That said, Gevo technology can use other types of fermentation sugars. While Gevo uses feed field corn to create isobutanol or ethanol and its co-product high-protein animal feed, there are other feedstocks that can also be used to produce the fuel. Beets are a traditional sugar crop that can be used to produce biofuels. Sugar cane has substantial carbohydrate energy and is already being used as a biofuel feedstock in Australia. Lignocellulosic resources include bagasse (sugarcane waste), woodslash (forestry waste), rice straw (agriculture waste in Asia), switchgrass, and corn stover (corn stalk waste). In many parts of the world, these materials are typically burned as waste, adding to greenhouse gas emissions and local air pollution without associated benefits.

Waste management is key to more sustainable agriculture. Some of Gevo's supplying farmers leave at least some stover in the fields, an approach we support, as this is one way to re-incorporate biomass and nutrients to the fields while using low- and no-till farming techniques.

In the U.S., the land used as "cropland" totals 391.5 million acres. Of that, the land used to grow food for people is 77.3 million acres, while that given over to livestock feed is 127.4 million acres. Cropland used to grow feedstock for ethanol and biodiesel totals 38.1 million acres, which is considerably less than the land left fallow to allow for soil recovery, 52 million acres. ("Here's How America Uses Its Land" by Dave Merrill and Lauren Leatherby, Bloomberg, July 31, 2018)

The bottom line is there's plenty of farmland being cultivated.

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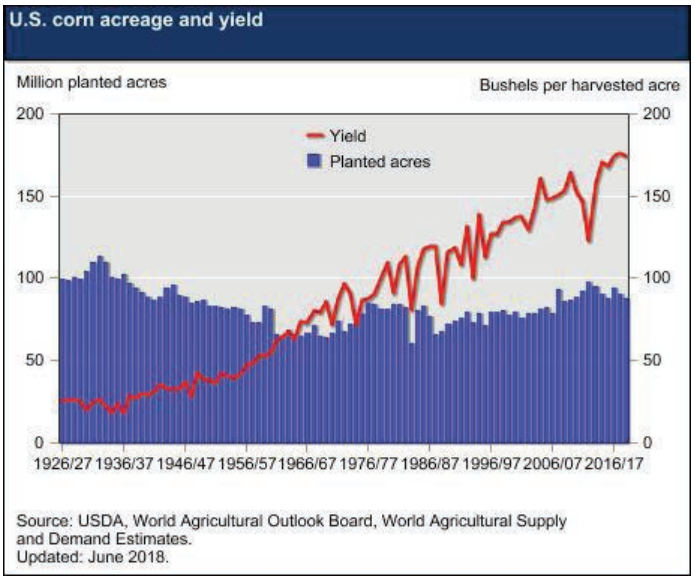

Gevo's method of making biofuel using feed corn uses the science of growing corn to improve yield per acre, helping partner farmers through improved farming methods that increase sustainability, reduce carbon intensity for the LCA, and augment yields. And, as explained above, Gevo rejects the either/or trade-off scenario, since an acre of corn can be used to grow corn for biofuels and livestock feed simultaneously.

Issue: *Is livestock healthier if it eats whole grains or grass?*

It depends on the livestock, but generally, cattle and hogs that are fed a high-protein diet lower in starch are healthier and yield leaner meat that's healthier for people to eat. The starch in whole-grain corn can present a problem for an animal species that evolved primarily to eat grass, especially those raised on grass and finished in feedlots. Farmers must take care not to overfeed cattle on grain, as they can become "grain sick" with dangerous gas, acidosis, and other conditions. All cattle produce methane as part of their digestive process (which they release through belching or flatulence). Cattle that are finished on corn reach market weight more quickly, and high-protein animal feed helps speed that process even more, while reducing the adverse impacts of feeding whole-grain corn.

Issue: *Didn't the adoption of ethanol as an oxygenate in reformulated gasoline zones (RFGs) cause a rise in food prices in the U.S.? Won't Gevo products do the same?*

The impact of ethanol on food prices in the U.S. in the first decade of this century is not clear, since factors including weather, markets, and energy prices all play a role in food prices. Published studies looking at fuel-price increases in 2007 and 2008 differ widely; some attribute no impact on food prices to ethanol production, while others attribute about two-thirds of food-price increases to ethanol. ("Ethanol Blamed for Record Food Prices" by Kevin Bullis, MIT Technology Review, March 23, 2011).

Government involvement in markets affects markets, often increasing price volatility. Gevo's biofuel production methods and the resulting high-protein animal feed products help to quell volatility due to Gevo's more sustainable co-product strategy for fuel and feed production.

Conclusion

Most of our direct interactions with corn place it in the category of food. The concept is as old as the popular imagery of the first Thanksgiving—corn and other agricultural products saving the Pilgrims from starvation. So, it is not surprising that some people assume that corn can only be used either as food or for something else. But that characterization sets up a false choice.

Using the starch from animal feed corn as a feedstock for biofuels can help save us from the climate impacts of fossil-fuel use for transportation, empowering people to move, travel, and transport goods in a more sustainable way. Corn has much more to offer than just one use.

At Gevo, we study the status quo and give ourselves the freedom to think beyond what has been done before. A new way of thinking about old things, like growing and using corn, backed up with innovative science and technology, economics, and an understanding of the market, is just what we need to create win-win solutions that optimize the best features of new and old systems. In this way, "or" becomes "and," and the best is yet to come.